FOOD AND NUTRITION BULLETIN

Volume 36, Number 1, March 2015

www.foodandnutritionbulletin.org

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Food and Nutrition Bulletin

Food and Nutrition Bulletin, vol. 36, no. 1

711 Washington St.–Mezzanine, Boston, MA 02111 USA
Tel.: (617) 636-3778
E-mail: FNB@inffoundation.org
www.foodandnutritionbulletin.org
ISSN: 0379-5721 (print)
ISSN: 1564-8265 (electronic)
Design and production by Digital Design Group, Newton, MA USA
Printed on acid-free paper by Webcom, Toronto, ON Canada

Can fortification be implemented in rural African communities where micronutrient deficiencies are greatest? Lessons from projects in Malawi, Tanzania, and Senegal

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Abstract

Background. *Fortifying common foods with micronutrients is an effective strategy for decreasing micronutrient deficiencies at a population level. National fortification initiatives often do not impact remote communities that are unreached by commercially produced food. The feasibility and sustainability of small-scale fortification as a mechanism to overcome this barrier are not well documented.*

Objective. *To document the process and assess the feasibility of implementation of community-based fortification of staple grains in rural communities in Malawi, Tanzania, and Senegal.*

Methods. *In the late 1990s, World Vision piloted community-level fortification within a large-scale, multicountry, integrated nutrition and health program. The exploratory approach focused on developing appropriate community-based methods and processes for flour fortification. An external review in 2012 documented the implementation process, identified barriers and enablers for sustainability and effectiveness, and evaluated the potential for replication and/or scale-up of the intervention.*

Results. *Strong advocacy influenced national policy and legislation for mandatory national-level fortification of staple grains. Piloting community-based fortification led to community acceptance of the consumption of fortified foods; however, lack of realistic funding mechanisms limited sustainability.*

Conclusions. *Despite the complexity and challenges of community-based fortification, it demonstrates great potential to address unmet needs for micronutrients in vulnerable populations. Further work is needed to determine contextually feasible and sustainable mechanisms for premix supply, quality control, and cost recovery. Incorporating community-based fortification into national fortification frameworks is recommended for countries where a significant proportion of the population may have very limited access to commercially fortified foods.*

Key words: Fortification, Malawi, micronutrients, nutrition, Senegal, Tanzania

Introduction

Hidden hunger, a chronic lack of vitamins and minerals in the diet, affects about one-third of the world's population. Deficiencies in micronutrients such as iron, zinc, and vitamin A compromise the physical and cognitive capacity of millions of people, contributing to the perpetuation of poverty, poor health, and underdevelopment [1]. The greatest burden of micronutrient deficiencies is found in low-resource communities where the typical diet is high in starches but low in micronutrients. Iron-deficiency anemia is the most common form of malnutrition, affecting over 2 billion people globally [2].

Fortifying commonly eaten foods with tiny quantities of essential vitamins and minerals is an effective strategy for decreasing micronutrient deficiencies at a population level and is widely practiced in high-income countries. Over the past 15 years, national governments and the global nutrition community have invested significant efforts to bring the benefits of fortification of staple foods to lower- and middle-income countries. Currently 81 countries have legislated mandatory fortification of wheat, maize, and/or rice, making a vital contribution to the global reduction of micronutrient

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deficiencies [3]. However, in many lower-income countries, particularly in South Asia and sub-Saharan Africa, a significant proportion of the population live in rural areas and rely on smallholder agriculture for their food supply, with limited access to the benefits of commercially fortified foods. Community-level fortification has the potential to extend the reach of national, large-scale fortification initiatives to rural communities.

Throughout this paper, "community-level fortification" is used as a collective term encompassing three different modes of decentralized food fortification. All three methods involve the addition of a multimicronutrient premix to grains either during or after milling. The premix is typically diluted with flour to form a preblend, which makes it easier to measure the quantities required to fortify small batches. *Medium-scale fortification* (MSF) mills process less than 40 metric tons (MT) per day and may have the capacity to make the preblend. *Small-scale fortification* (SSF) hammer mills process small volumes (less than 20 MT/day, often as little as 1 MT/day) of high-extraction flour. Measured amounts of micronutrient preblend may be added during milling or mixed in afterwards, but SSF units cannot make the preblend. *Home fortification* (HF) is the addition of micronutrient preblend in a sachet or measured scoop to a food during meal preparation [4].

In the late 1990s, World Vision began to investigate the potential of community-level fortification within MICAH, a large-scale, multicountry, integrated nutrition and health program funded by the Canadian International Development Agency. The initial objective was to explore the technical feasibility of fortifying maize at hammer mills in Malawi. Once a viable technical method was identified, the focus shifted to exploring the operational and logistic feasibility of implementing community-level fortification through pilot test projects in Malawi and Tanzania, and later in Senegal. The overall aim was to increase access to micronutrients in rural communities. The fortification initiatives evolved over the implementation period as new challenges were encountered. Mechanisms for the initiative to be financially self-sustaining were introduced later in the process. On MICAH's conclusion, private funds were used to extend the initial pilot tests. This paper presents the findings of a review conducted in 2012 to document the implementation process; identify barriers and enablers related to implementation, sustainability, and effectiveness; and evaluate the potential for replication and/or scale-up of the intervention.* The review included key informant interviews with project leaders and advisors, review of reports from the three projects, and site visits, including focus group discussions with community members in Malawi and Tanzania. Cost analysis was outside the scope of the review.

* Klaas N, Mildon A. World Vision fortification review. Consolidated case study: Malawi, Senegal and Tanzania. Unpublished report, World Vision Canada, 2012.

Methods

The fortification initiatives in all three countries were embedded within a broader nutrition and health program (MICAH), which facilitated community engagement, capacity-building, and social mobilization. As the coordinating agency, World Vision provided funding, technical expertise, a larger financial and management framework, and monitoring and accountability mechanisms. Highly motivated national staff committed time, energy, resources, and creative thinking into developing necessary policies, procedures, systems, and networks. Extensive capacity-building and technical support at the national, district, and village levels strengthened commitment and quality of implementation.

Within this broader common framework, each project had unique features and adaptations based on the local context.

Malawi (1998–2009)

National context

In 1998, when the fortification initiative began, the government of Malawi was discussing the extension of fortification from the iodization of salt to include other staple foods. World Vision staff led the formation of the National Fortification Technical Committee comprising representatives from the Ministry of Health and Population, universities, nongovernmental organizations (NGOs), and technical experts. This committee developed guidelines for fortification and later became the National Fortification Alliance (NFA). The advocacy efforts of the NFA influenced national policy in favor of fortification, including removing import tariffs on fortificants and equipment, and laid the groundwork for the planned legislation of mandatory large-scale fortification of wheat and maize.

Social mobilization

Initially, the target communities were not familiar with fortification, and there was a common perception that it was a contraceptive initiative. Social mobilization activities led by strong networks of community partners, which were already well established through the MICAH program and trusted by the communities, facilitated the introduction and acceptance of fortification. Village coordination committees, composed of village health workers, healthcare providers, community leaders, and volunteers, were trained by project staff. They sensitized and educated community members through drama, dance, song, discussions, and demonstrations. Community members observed positive outcomes when undernourished children were fed fortified complementary foods and saw no adverse effects in adults consuming fortified maize flour. The comprehensive public awareness campaign and behavior change communication overcame initial wariness regarding fortification, increased demand, and facilitated its broad acceptance.

Implementation process

The fortification initiative began in collaboration with a local mission that was already working closely with MICAH to implement other nutrition and health activities. MICAH supported the purchase of a hammer mill, a roaster, a winnower, a blender, packing equipment, and a truck, then built the infrastructure to house the mill, offices, a storage room, and a garage on the mission's land in order to establish an MSF unit. By beginning at one mill, initial testing of equipment and methodology was facilitated before expanding to a second MSF unit connected with a mission hospital in another region of the country. World Vision consulted with fortification experts to select the micronutrient premix formulation, which each MSF unit then independently sourced from a private supplier in South Africa. The MSF units diluted the premix with maize flour to produce a preblend that was then added to both maize flour and *likuni phala*, a complementary food targeted to young children but consumed by the whole family. The MSF units produced these fortified products for sale to institutions, hospitals, and NGOs, as well as making preblend sachets for household use.

Consultants assisted in developing a business plan* focused on productivity, profitability, and sustainability for one of the MSF units, to address the challenge of absorbing costs formerly paid by donor funds. Strategies included reviewing organizational structures, staffing, and training to optimize efficiency and productivity; developing short- and long-term sales, markets, and production objectives to decrease dependence on preblend income; projecting financial trends based on present and future markets; and investing in mass media social marketing campaigns with the potential of reaching more customers. However, because the MSF unit was embedded in a charitable mission, most staff did not have a business background and lacked the capacity to fully implement the business plan. Ongoing challenges included staff turnover, management capacity, and lack of personnel with marketing skills and experience.

In 2001, after 3 years, the project expanded to include SSF. With MICAH project funds, the MSF units produced preblend that was distributed to nine local hammer mills in three regions of the country. Distribution was expanded to 19 mills by 2005. Millers received training on techniques, procedures, and benefits. Extensive work was invested to develop and manufacture a dosifier that accurately added premix to the maize as it was being milled, thus ensuring a more homogenous mix and reducing the amount of time required by the women to hand-mix the premix in the milled grain. Monitors, trained and paid by the project, were based at the hammer mills to monitor processes and promote fortification to clients. Initially, no charge was passed on to the consumer or the miller.

During this time, HF was also piloted as an implementation model. Community Public Health Chairmen purchased preblend sachets from the MSF units and distributed them to community fortification volunteers. In addition to distributing preblend to households, the volunteers trained community members on proper addition, mixing, and storage of the sachets and monitored their use.

With frequent breakdown of milling equipment and millers receiving no economic advantage from fortifying, the SSF at local hammer mills was discontinued in 2007, while some communities continued to promote and sell preblend sachets for HF.

Quality assurance and control

Quality assurance systems and standards were developed, yet there was low capacity in the country for monitoring and enforcement. The MSF units were licensed and monitored by the Malawi Bureau of Standards, which performed quarterly quality audits. These audits examined all aspects of production, including equipment, buildings, raw material storage, packaging, staff hygiene, and medical records. Samples of fortified products were evaluated quarterly for micronutrient and moisture contents, quality of blending, color, and taste. However, feedback was often delayed and was not always conclusive. Several fortification and milling experts visited the MSF units to assess the quality control systems, which led to adjustments in equipment and processing techniques.

SSF monitors supervised the preblend addition process and performed iron spot tests for quality assurance, a simple, inexpensive technique requiring little training and done at the mill. Regional project coordinators audited records, production, quality control, and inventory control. At the village level, volunteers monitored the use of preblend sachets for HF. However, further quality control measures could not be implemented practically due to the rural location of the communities participating in SSF and HF activities.

Cost recovery

Initially, the MICAH project covered all costs, and no charge was passed on to millers or consumers. As the fortification initiative developed, profits from the sale of likuni phala and creamed maize by the MSF units helped to cover the cost of producing preblend sachets

* Radford KB. Domasi fortification unit business plan, analysis and recommendations. Unpublished report, World Vision International, 2005.

for HF. A plan was established to sell the HF sachets in the communities at a subsidized rate. Each sachet fortified 2 kg of maize and was sold by fortification volunteers to community members for approximately US$0.02 (7 to 10 kwacha). These funds were used as a part of a savings and loans bank for the community to obtain more sachets. The MSF units were also able to subsidize the cost of preblend for SSF. However, when a cost recovery plan for SSF was introduced, it was not adequate to cover all production costs and was met with resistance by consumers.

Coverage

In 2001, nine SSF units began fortifying maize, benefiting 9,500 households in three regions of the country. By 2005, SSF had expanded to include 19 mills, reaching 26,500 households, but it was discontinued in 2007 due to technical and financial challenges. Production levels at the MSF units varied due to a variety of factors. Management issues and the transition from charity to business affected production. One MSF unit expanded production of fortified likuni phala from 36 MT in 2000 to 408 MT in 2010. When this MSF unit introduced a cost recovery program, staff observed a decline in demand for preblend sachets. However, in 2011, 2 years after project funding ended, the other MSF still produced approximately 725 MT of preblend sachets annually, sufficient to fortify maize for approximately 10,000 households per month.

Status in 2012

Although SSF was discontinued several years earlier, in 2012 the MSF units continued to produce fortified products for commercial sale and to provide preblend sachets for HF to local communities at a subsidized cost. One MSF was producing preblend sachets for 10,000 households, while the other had greatly declined production as a result of challenges to operating a profitable business within the charitable mission context.

Summary

In Malawi, all three types of community-level fortification were implemented. The MSF initiative facilitated the development of procedures, standards, and interest in fortification at the village level. Project funds supported expensive infrastructure and start-up costs. Preblend produced by two MSF units supported SSF and later the use of preblend sachets for HF. Strong social mobilization and education resulted in broad interest and acceptance of fortification. However, technical challenges (equipment failure) and the late introduction of a cost recovery system, which was unable to produce financial autonomy, led to the cessation of SSF activities. The MSF units continued to produce fortified products for commercial sale and preblend sachets for HF use.

All three fortification methods faced monitoring and quality control issues. Although the MSF model was viable from a technical and possibly financial perspective, a stronger business model was needed. SSF did not appear viable due to technical and financial reasons. HF appeared viable with the support and subsidy of the MSF units.

Tanzania (2001–2009)

National context

In 2001, when the MICAH program began to pursue fortification initiatives, Tanzania had no national fortification legislation. MICAH staff developed collaborative partnerships with the Ministry of Health, universities, NGOs, and technical experts to establish fortification procedures and policies. These networks became instrumental in establishing the NFA, which successfully advocated for national fortification of wheat, maize, and vegetable oil. This legislation was passed in 2011.

Social mobilization

In rural communities, maize was traditionally milled in small quantities at local hammer mills, but fortification was not a familiar concept. It was initially viewed with suspicion as a potential contraceptive intervention. Social mobilization and training for the fortification initiative were conducted through community networks previously established by the MICAH program. Extensive behavior change communication through demonstrations, discussions, examples, dance, drama, and song corrected false perceptions and led to acceptance of and increased demand for fortification.

Implementation process

SSF was initially implemented in hammer mills. MICAH program staff sourced preblend in large quantities from the national Seventh Day Adventist Mission in Arusha, which operated a food production branch to fulfill the dietary guidelines of their beliefs. MICAH staff repackaged the bulk preblend into sachets containing the appropriate amount to fortify 1 kg of maize and then delivered the sachets to hammer mill operators. Later, the supplier produced these premeasured preblend sachets. The mill operators contributed the milling and mixing space but had no obligation to fortify and did not receive any economic advantage. HF was also introduced, giving beneficiaries the option to fortify their maize at the hammer mill or in their home. Preblend sachets were sourced and delivered to communities by project staff. Fortification committees composed of village health workers and community members were established in each community. Trained by project staff, they were responsible for the supply and delivery of premix within the community, educating families on proper mixing, and monitoring the use of premix. Eventually, SSF was stopped due to equipment breakdowns and lack of incentives for millers to continue the effort; however, HF continued.

Quality assurance and control

Samples from the mills and later from the communities were tested periodically at a university laboratory. However, there was no consistent system for quality assurance, and although monitoring was done at the community level, it lacked the rigor necessary to ensure consistent results.

Cost recovery

The costs of fortifying maize at the hammer mills were initially fully covered by the MICAH program, although millers received no remuneration for fortifying and donated the space and their time. In building toward a more viable plan, beneficiaries began to pay approximately US$0.01 (20 Ts) per 10-g sachet (sufficient to fortify 1 kg of maize through either SSF or HF), which only partially covered the implementation costs. However, the history of free distribution of preblend at the beginning of the project resulted in the need for considerable sensitization to achieve acceptance of this minimal cost-sharing initiative. The charge was not increased further over time, and the fortification costs continued to rely heavily on project funding.

Coverage

SSF initially benefited 9,350 households, expanding to 22,950 households in 4 years through a combination of SSF and HF. When SSF stopped and a cost recovery scheme for HF was introduced, coverage fell below 2,000 households, but after extensive social mobilization and training, it grew to 4,600 households, where it remained through the end of funding in 2009.

Status in 2012

As project funds ended, communities did not have the capacity to continue fortification activities. Remote communities had limited access to the necessary communication technologies, networks, knowledge, technical expertise, and financial reserves to independently procure preblend sachets and oversee implementation. Furthermore, the income from the sale of preblend sachets at a highly subsidized rate covered only a small proportion of the purchase cost, excluding transport, storage, and distribution costs, and no other source of funding was available. Therefore, technical staff supported the communities to develop a food-to-food fortification initiative. They combined, dried, and ground selected types of locally available foods to produce a mix that was cooked into a porridge. Fortification committees actively promoted and monitored this initiative. However, during the 2012 review, community leaders and members expressed great interest in reestablishing flour fortification.

Summary

Both SSF and HF were implemented in Tanzania, and the flexibility to adapt methodologies enhanced coverage. The integration of fortification within a broader health and nutrition program enhanced community acceptance, facilitated the partnership for premix supply, and contributed to the national fortification agenda. Technical challenges with hammer mill breakdowns and the lack of economic incentive for millers led to the cessation of SSF, while HF continued until project funding concluded. Although the communities did not have the capacity or resources to continue HF without external support, the need for dietary enhancement was recognized, and food-to-food fortification was implemented instead.

Senegal (2004–2006, 2008–2012)

National context

Fortification activities were initially developed in the final years of the MICAH program (2004–2006), then were recommenced with private funding in 2008, and integrated with a US Agency for International Development (USAID)-funded multi-NGO community health program until 2012. During the initial phase, the NFA was already well established, and it launched a 5-year national fortification strategy in 2006 [5], which led to legislation mandating the fortification of wheat and oil by large-scale producers. However, the World Vision project pioneered the concept of community-level fortification, which was not included in the national framework.

Social mobilization

Remote communities where World Vision was operative were not familiar with fortification when the pilot test started. Public awareness and communication activities facilitated its introduction and acceptance in the communities. Networks of community partners were sensitized and educated on the purpose, process, and benefits of fortification. Community committees were formed as partners in the implementation and monitoring of fortification activities. Acceptance of fortification was high in the target communities, with demand for preblend regularly outstripping supply.

Implementation process

The project piloted an approach combining health, nutrition, and economic development activities. Initially, two mills were built to process grain, offering communities an alternative to the traditional method of pounding grain to make flour. The mills were run as community-managed businesses, with mill operators retaining any profits. The milled or pounded grain was fortified in the home using preblend provided to households in monthly batches. The project also constructed two small buildings, known as fortification units, for storing and diluting premix, and two bakeries, which produced bread made from fortified flour for sale in the communities. The fortification units were staffed by volunteers who were selected and supervised by community management committees. The bakery staff was paid and bakery profits were managed by community fortification management committees for future premix procurement. Fortified flour was also sold at a subsidized rate to local schools for use in meal preparation.

The project used a premix available from a commercial supplier in Dakar. The communities, with supervision by project staff, became responsible for the dilution of premix at the fortification units and the monthly distribution of preblend to households and schools. However, the difficulty of obtaining an appropriate sieve to efficiently process millet resulted in a more labor-intensive preblend production process, which decreased output and expansion potential. Seasonal food insecurity posed another major challenge. July to September is the lean season when staple cereal grains are in short supply, so fortification activities were significantly reduced during this period each year.

Quality assurance and control

The Institut de Technologie Alimentaire (ITA), the national food technology agency, provided training, technical support, and quality control monitoring for the project. ITA staff traveled to the remote project location two or three times per year to collect samples of fortified flour for analysis. They also analyzed samples of fortified foods before and after cooking to determine micronutrient contents. The level of iron was consistently higher in the fortified than in the unfortified flour but varied depending on the mixing technique and the type of grain used [6].

Cost recovery

From inception, fortification was envisioned as a microenterprise initiative that would become financially self-sufficient. The plan was that the sale of fortified bread from the bakeries would cover the cost of premix procurement and free distribution of preblend to households, as well as the wages of bakery staff. However, the transition from full reliance on project funding to a self-sustaining initiative was incomplete when external funding ceased, and fortification activities did not continue.

Coverage

The pilot project reached over 750 households across 32 communities. Three secondary schools and 12 primary schools also used fortified flour in at least one meal per day for boarding students.

Status in 2012

A strategy for continuing fortification activities without external funding was developed in the final year of the project (2012). The intention was to generate sufficient profits through the sale of fortified bread to allow the community management committees (formed as income-generating enterprises) to independently purchase premix. Volunteers would continue premix dilution at the fortification units established by the project. Community committees would also continue their premix distribution and monitoring activities using bicycles provided by the project. An independent project evaluation in October 2012 found that the committees were insufficiently prepared and resourced to fulfill these roles, particularly sourcing and transporting premix from Dakar,* and indeed fortification activities have not continued 1 year after the end of funding (personal communication with Babacar Ndour, Health Programme Manager, World Vision Senegal, December 2013).

Summary

The fortification initiative in Senegal piloted innovative methods to improve access of remote villages to fortified products through a combination of health, nutrition, and income generation activities. Although fortification was well accepted in the target communities, seasonal food insecurity caused a major reduction in activities from June to October each year. The project set up mechanisms for continuation of the initiative through strong community ownership, particularly in the areas of premix dilution and distribution, social marketing and monitoring, and a financial plan for bakery sales to fund other fortification costs. However, at the end of funding, the income-generating mills and bakeries were not yet financially stable. Community committees were insufficiently prepared and resourced to source and transport the premix from Dakar to their remote communities, and fortification activities were discontinued.

Results

Community-level fortification, a novel method of increasing micronutrient intakes of rural populations, was implemented in three different country contexts. The pilot tests were not designed to evaluate the effect of community-level fortification on micronutrient status, but to explore the feasibility of implementation. The strengths and challenges related to World Vision's experience with the three implementation modes (medium-scale fortification, small-scale fortification, and home fortification) are outlined in **tables 1** and **2**.

In addition to exploring the feasibility of implementation, the projects were instrumental in raising awareness of the need for and benefits of fortification,

*Tendeng CA. Final evaluation of the flour fortification project in Velingara, Senegal. Unpublished report, Dakar: World Vision Senegal, 2012.

TABLE 1. Implementation strengths of community-level fortification pilot tests

Country	Medium-scale fortification (MSF)	Small-scale fortification (SSF)	Home fortification (HF)
Malawi	Production capacity for commercial sales	Enhanced reach of fortification; first trial using preblend in community setting	Mobilization of community committees and volunteers for social mobilization, monitoring, and sachet distribution
	Registered business subject to regulation and quality control monitoring	Mobilization of community committees and volunteers for social mobilization and monitoring	Affordable by consumers, with benefit of MSF subsidy
	Supported SSF and HF through bulk premix imports, packaging, and subsidized sale of preblend	Dosifier designed to add preblend directly during milling, eliminating the need for post-milling mixing	Enhanced community knowledge and engagement in addressing micronutrient deficiencies
Tanzania		Preblend sachets eliminated need for measurement at mills	Enhanced coverage: easier to expand HF to new communities than engage new mills in SSF
		Mobilization of community committees and volunteers for social mobilization and monitoring	Mobilization of community committees and volunteers for social mobilization, monitoring, and sachet distribution
			Enhanced community knowledge and engagement in addressing micronutrient deficiencies
Senegal		Expanded reach of fortified foods (schools, bakeries)	Suitable for use with different grain processing methods (milling or pounding)
		Potential to subsidize HF preblend costs	Mobilization of community committees and volunteers for social mobilization, monitoring, premix dilution, and preblend distribution
		Provided income-generating opportunities	Enhanced community knowledge and engagement in addressing micronutrient deficiencies

particularly in Malawi and Tanzania, where they played a key role in establishing National Fortification Alliances in partnership with the respective Ministries of Health. The work of the NFAs influenced national policy and led to legislation for mandatory national-level fortification of staple grains. However, for logistic reasons, this legislation did not extend to community mills, and community-level fortification remains outside the national fortification framework in Malawi and Senegal. Tanzania's National Nutrition Strategy for 2011–2015 [7] committed to developing a fortification plan and mentioned the need for exploration of community-level fortification. Nonetheless, the community-level fortification projects did benefit from policy directives removing tariffs on imported premix and fortification equipment in all three countries, and from access to technical expertise and quality control monitoring services associated with the NFAs, particularly in Senegal. Embedding the community-level fortification pilot tests within broader nutrition and health projects provided an overarching framework of institutional support for management, coordination, capacity-building, and technical expertise, as well as financial resources, partnerships, and networks both in-country and globally. The relationships, nutrition knowledge, and trust already built in the target communities through the MICAH program facilitated social mobilization activities and acceptance of the benefits of fortification. However, the communities were not adequately engaged in decision-making and implementation leadership from the outset of the fortification pilot tests. Consequently, the capacity and confidence for problem-solving and independent leadership were not sufficiently developed when World Vision funding ended.

Continuation of community-level fortification without external funding was very limited due to inadequate cost recovery mechanisms and underdeveloped

TABLE 2. Barriers to feasibility of implementation of community-level fortification pilot tests

Country	Medium-scale fortification (MSF)	Small-scale fortification (SSF)	Home fortification (HF)
All 3 countries		Not supported by national fortification agenda and legislation Inadequate financial sustainability planning from outset Costs and logistic challenges to sourcing and transporting preblend to multiple remote communities Costs and logistic challenges of regular quality control monitoring in rural communities	
Malawi	Mixed mandate (charity vs. business) compromised production potential Low institutional capacity for rigorous, accurate quality control monitoring	Extra workload with no economic incentive for millers Frequent mill equipment breakdowns Late introduction and insufficiency of cost-sharing measures	Transportation access to MSF sites to obtain preblend sachets
Tanzania		Extra workload with no economic incentive for millers Frequent mill equipment breakdowns Late introduction and insufficiency of cost-sharing measures	Lack of effective cost-recovery mechanism
Senegal		Seasonal food insecurity (June–October) significantly reduced access to staple grains Lack of appropriate sieve for processing millet reduced production potential Late introduction of plans for continuity; inadequate capacity-building and financial resources for communities to implement	Seasonal food insecurity (June–October) significantly reduced access to staple grains Free preblend distribution dependent on subsidy from external funds or other income-generating activity

community capacity to implement and monitor all phases of the initiative. In Malawi, hammer mill fortification was discontinued, while the two MSF units continued to produce preblend sachets for sale to local communities, although demand declined when cost recovery measures were introduced. The MSF units continued to produce fortified products for sale to institutional buyers. In Tanzania, although community interest in fortification remained high, cost recovery measures and community capacity were insufficient to sustain activities. Food-to-food fortification was prioritized instead. In Senegal, continued potential for community-based fortification remains with established facilities and equipment. Although a sustainability plan was developed, this was done late in the project, and fortification activities ceased with the end of project funds.

Discussion

In the late 1990s, when the Malawi and Tanzania projects began, few lower-income countries had fortification programs in place, but the concept was beginning to attract interest at both national and global levels. International goals set at the 1990 World Summit for Children (UNICEF) focused attention and resources on the huge burden of preventable micronutrient deficiencies. As national networks for fortification were established and began to formulate strategies, organizations working at the community level recognized that the rural poor would be largely excluded from the benefits of large-scale food fortification. Pilot projects of community-level fortification were launched by NGOs in at least four African countries, and the Micronutrient Initiative provided technical support, feasibility studies, and knowledge-sharing forums. However, with the obvious benefits and easier implementation feasibility of large-scale commercial fortification, attention increasingly focused on supporting national fortification initiatives, and most community-level efforts were discontinued.

Technical standards and guidelines for large-scale fortification have now been developed [8], and more technical expertise is available, including tools to support the design of evidence-based fortification programs [9]. However, community-level fortification continues to be perceived, not without justification, as overly complex and cost-ineffective [10], despite the acknowledgment that national fortification initiatives exclude a significant nutritionally vulnerable proportion of the population [11].

Developing sustainable fortification models suited to smallholder agricultural communities is challenging [12]. Maize flour, the staple grain of Malawi, Tanzania, and several other sub-Saharan African countries with a high burden of malnutrition, has been identified as one of the most costly staple foods to fortify due to the large number of mills that need to be equipped and monitored [13]. The logistic challenges of establishing a reliable premix supply and conducting adequate and regular quality control monitoring are magnified in rural areas.

World Vision's experience implementing the three pilot test projects demonstrates the complexity of implementing community-level fortification, identifying many challenges but also a few key success factors that offer promise for greater success in future initiatives. With the support of project resources and leadership, community-level fortification activities were established in various forms in the different contexts. The chosen methods of fortification were adapted to the local situations and were well accepted by the communities. The projects engaged existing national resources for implementation guidance, premix supply, and quality control, as well as leveraging community confidence, organizational structures, and nutrition knowledge built through the broader MICAH program. However, national fortification initiatives did not accommodate tangible support for community-level fortification, so that sustainability relied on the communities' ability to fund and manage the fortification activities themselves upon the completion of project funding. In addition, the remote location of the target communities exacerbated logistic challenges related to premix supply and quality control, which were not resolved in any of the three contexts when project funding ceased. There was limited focus on establishing and monitoring a viable financial sustainability plan from the outset of the project, so when ad hoc cost recovery mechanisms were introduced late in the process they proved inadequate to ensure ongoing financial viability. A fundamental issue for SSF is the absence of economy of scale, so that full cost recovery is not achievable from payments for fortification by end users. Large-scale commercial food enterprises with inbuilt mechanisms for quality control, marketing, and distribution can achieve economies of scale that minimize the additional cost of fortification to consumers. In contrast, village hammer mills process small volumes of maize on a fee-for-service basis. Adding the cost of premix procurement, transport, and storage, as well as quality control testing, to the milling fee represents an unaffordable cost increase to the consumer. In addition, SSF mills are usually operated by a staff of only one or two millers, who must assume the additional work of obtaining and storing the premix, participating in quality control testing, and promoting fortification to customers. In the absence of enforced legislation mandating fortification, this requires exceptional motivation and commitment on the part of the millers, who will likely end up at a competitive disadvantage compared with mills not practicing fortification [14]. In both Malawi and Tanzania, the lack of incentives for millers, frequent equipment breakdowns at the hammer mills, and community resistance to the introduction of cost recovery measures contributed to the discontinuation of SSF. In the MICAH Malawi project, the additional workload for millers was offset by the project's hiring monitors to promote and oversee the fortification activities, but this approach could not be sustained without the funding and support of the project.

MSF, implemented only in Malawi, proved more viable and continued in the two units after the end of project funding. Medium-scale mills typically serve a regional rather than a highly localized market, are usually private businesses with 3 to 10 employees, and have the capacity to produce more than one milled product at a time [4]. For the two MSF units partnering with the MICAH program in Malawi, this greater capacity allowed the production of fortified foods for commercial sale, which supported operating costs and reduced the additional cost of fortification. This potential could have been enhanced further with a stronger business model. The MSF units also provided a support system for SSF and HF in Malawi by importing premix in bulk and producing preblend for the SSF mills and for HF. The MSF units subsidized the cost of sachets for HF, which were then sold at an affordable price in the local communities. Quality control measures can more easily be implemented for MSF units, which are more likely to be registered businesses obliged to comply with food-processing regulations, in contrast to SSF mills, which are typically nonregistered microenterprises. However, any quality control program is limited by the existing legislative framework and the in-country capacity for implementation and monitoring.

HF in Tanzania and Senegal was implemented without a supportive MSF structure. Although HF was successfully implemented during the pilot test period, it did not continue in either context after project support ceased. This was due to both financial and operational barriers. The project framework provided a variety of resources, including finances, management and supervision, access to transportation, and relationships with industry and government. It was not possible for community members in remote locations to assume full ownership of the HF activities without any of this supportive framework in place. In Tanzania, a cost recovery scheme was introduced, with the intention that the sales of preblend sachets in the community would cover the cost of future purchases, but consumers had difficulty accepting even a minimal cost-sharing plan, and demand dropped when the charge was introduced. Furthermore, the community fortification committees did not have access to transportation to procure the sachets and did not have a relationship with the supplier. Similarly, in Senegal, the project was located far from the capital city, and the community members did not have access to transportation to make this journey to negotiate with the supplier and purchase new supplies of premix. Although capacity was built to make the preblend and the sales of fortified bread were expected to cover the cost of premix for HF, the difficulties of accessing the premix were too great and fortification was discontinued.

While it proved unfeasible for communities to sustain fortification on their own, the project in Malawi identified the potential for MSF to provide a supportive structure for SSF [15]. This approach is being pursued by Sanku Fortification, a new initiative focused on developing viable methods of community-level fortification [16].

Sanku developed innovative technology to address some of the key technical and operational challenges to hammer mill fortification. These include millers' workload, human error in measuring and mixing, sanitation concerns, logistic barriers to conducting quality control testing in remote locations, and lack of guarantee that millers actually use the premix. This technology for gravimetric dosing of a highly concentrated premix directly into hammer mills is similar to that used at the large scale. A miller simply opens the 5-kg aluminum bag and pours the concentrated premix into the dosifier. There is no need for the miller to perform any additional tasks or to dilute the premix further. The dosifier stores operational data, such as hours and days of operation, amount of grain milled, and amount of premix dispensed. These data are easily retrieved and used for monitoring the homogeneity and use of premix and ensuring good practices. By comparing the amount of premix a mill receives and consumes with the remaining stock, the miller's compliance with fortification standards can be assessed. The data can also be used to map consumption patterns of fortified flour in a region.

At the MSF level, the increased cost of fortification is negligible due to economy of scale, providing a platform from which to support and subsidize SSF. In Tanzania, for example, Sanku calculated that the cost of purchase and transport of premix for MSF of maize flour is 0.27% of the average annual household income. Although this figure does not include the one-time purchase of dosifier and ongoing promotional and monitoring costs, it suggests that MSF can be financially viable. The advantage of scaling up a SSF program in countries that have mandatory fortification legislation is that active social marketing and a certain level of market demand would already be present.

By leveraging the networks, systems, and tools already in place for large-scale fortification, Sanku aims to expand the reach of fortified flour first through MSF units and then to SSF, beginning in Tanzania but with the expectation of replication in other East African countries (personal communication from Felix Brooks-Church, Founding Technology Officer, Sanku Fortification, December 2013).

This renewed interest in SSF, with its concerted effort to resolve challenging issues related to accurate dosing, monitoring, and logistics, offers great potential to improve the nutritional status of the more vulnerable rural populations. However, a persistent limitation is the lack of research on the efficacy of fortification delivered through hammer mills or HF sachets. The three pilot tests led by World Vision focused entirely on implementation issues, but as new initiatives explore innovative solutions to implementation challenges, it will be important to establish the efficacy, effectiveness, and scalability of community-level fortification.

Conclusions

Community-level fortification of staple grains is very challenging to implement in rural communities of sub-Saharan Africa. However, this innovation has great potential to address the unmet need for micronutrients in vulnerable populations. World Vision's experience demonstrates the acceptability of community-level fortification and the potential for implementation models to be developed. Further work is needed to determine contextually feasible and sustainable mechanisms for premix supply, quality control, and cost recovery. Because the complexity of small-scale fortification places high demands on community capacity, it may be best developed and supported through medium-scale initiatives, which can also serve as a support base for home fortification. Incorporating this work into national fortification frameworks is recommended for countries where a significant proportion of the population has very limited access to commercially fortified foods.

Authors' contributions

Alison Mildon and Naomi Klaas authored the manuscript. Naomi Klaas led the review of community-level fortification projects, Alison Mildon and Naomi Klaas co-led the interpretation of results, and Alison Mildon led the development of the discussion. Melani O'Leary gave oversight to the review of fortification projects and reviewed and edited the manuscript. Miriam Yiannakis gave leadership to implementation of the pilot test in Malawi and provided technical expertise to the project review and manuscript development. All authors approved the final manuscript.

Acknowledgments

The authors express their appreciation to the project managers, staff, and communities involved in the innovative fortification projects. Their willingness and hard work contributed to the development of this novel approach to address micronutrient deficiencies. Thanks to the technical people who provided insight, technical assistance, and support through the review of this paper, especially Babacar Ndour of World Vision Senegal, Felix Brooks-Church of Sanku Fortification, and Quentin Johnson of Quican Inc. The MICAH program in which the small-scale fortification initiatives were embedded was funded by the Canadian International Development Agency and World Vision Canada.

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Folate status and intake of tribal Indian adolescents aged 10 to 17 years

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Abstract

Background. *Adequate folate intake and levels are advisable throughout life but are of particular importance during adolescence, a period of rapid growth. However, folate insufficiency in economically deprived Indian adolescents is understudied.*

Objective. *This cross-sectional study examined the prevalence of folate deficiency and adequacy of folate intake of 224 tribal Indian adolescents (10 to 17 years of age). The secondary aim was to study the association between anemia status and folate status.*

Methods. *Radioimmunoassay, multiple-pass 24-hour dietary recall, and HemoCue were used to measure red blood cell (RBC) folate, folate intake, and anemia status, respectively.*

Results. *The geometric mean (95% CI) RBC folate concentration (nmol/L) was 360.2 (329.7 to 393.6), and the mean ± SD folate intake (μg/day) and hemoglobin level (g/L) were 159.9 ± 44.7 and 125.4 ± 13.0, respectively. Almost half of boys and girls aged 10 to 12 and 13 to 15 years and 66.7% of girls aged 16 to 17 years were deficient in RBC folate (< 340 nmol/L). The mean ± SD folate intake (μg/day) of girls (139.4 ± 34.5) was lower than that of boys (173.8 ± 45.5) (p < .001). With respect to adequacy of folate intake, a greater proportion of girls in the age group of 13–15 years (78.5% vs 38.6%, p < 0.001) and 16–17 years (100.0% vs 76.9%, p = 0.04) had intakes below their Recommended Dietary Allowance (RDA). No association was observed between folate intake and RBC folate deficiency or between anemia status and RBC folate deficiency.*

Conclusions. *Folate insufficiency was widespread in tribal Indian adolescents. There is an urgent need to develop culturally sensitive strategies for improvement.*

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Key words: Adolescents, anemia, folate intake, Indian, red blood cell folate

Introduction

In India, nearly half (47%) of adolescent girls and 58% of adolescent boys aged 15 to 19 years are underweight (body mass index [BMI] < 18.5 kg/m^2) [1]. Underweight status could reflect inadequate nutrient intake and thereby increased susceptibility to nutritional deficiencies [2]. In India, the prevalence of micronutrient deficiencies is high, given that the diets are predominantly cereal based. According to national Indian data for 2009, all girls and 92% of boys aged 10 to 17 years consumed the suggested amounts of cereals and millets (240 to 330 g/day for girls and 300 to 450 g/day for boys) [3]. In contrast, none of the boys or girls consumed the suggested amounts of green leafy vegetables (100 g/day) and fruits (100 g/day) [3]. This is of particular interest in this paper, as green leafy vegetables and citrus fruits are among the important natural sources of folate in Indian diets, which are predominantly vegetarian [2, 4].

Folate is obtained from the diet, as it cannot be synthesized by humans [5]. As a coenzyme it plays an integral role in amino acid and nucleotide metabolism. Specifically, folic acid is required for the synthesis of methionine from homocysteine [6]. High levels of homocysteine in childhood are an independent risk factor for cardiovascular and cerebrovascular diseases in adulthood [5, 7]. Folic acid is also essential for the biosynthesis of DNA and RNA and therefore is vital for erythrocyte production. Folate deficiency is manifested clinically as megaloblastic anemia [6]. When the rate of cell synthesis increases, folate requirement increases. Adolescence, the stage of the second-highest growth rate after infancy, is a crucial stage that requires an adequate intake of folate [8]. Consuming the recommended amounts of folic acid and maintaining adequate levels is of particular importance for females, especially during pregnancy due to associated birth defects, specifically neural tube defects [8, 9]. A recent meta-analysis of 19 studies conducted in India reported a total of 308,387 births, among which neural tube defects were identified in 4.1 of 1,000 births (95% CI, 3.1 to 5.4) [9]. Nearly all studies examined in the meta-analysis were conducted in government hospitals, which mainly cater to the lower socioeconomic strata [9]. This is in line with previous research, which has indicated that nonaffluent and rural people may be at greater risk for folate deficiency than affluent and urban people [4, 10].

There is a dearth of literature examining the prevalence of folate deficiency and adequacy of folate intake in economically deprived, healthy (without chronic diseases) Indian adolescents. Only two studies were identified that examined red blood cell (RBC) [11] and serum [12] folate deficiency in 869 and 1,037 urban, affluent, healthy Indian children aged 5 to 18 years, respectively. Sivakumar et al. [11] showed that all children were deficient in RBC folate (< 550 nmol/L), and Kapil and Sareen [12] reported that 38% of children 12 to 18 years of age had serum folate deficiency (< 6 nmol/L). In addition, there is a scarcity of research investigating the association between folate intake and folate status in the Indian scenario. The present study examined the prevalence of folate deficiency and the adequacy of folate intake in tribal adolescents aged 10 to 17 years. The study also investigated the relationship between dietary folate and RBC folate status of the participants.

In India, the national data report the prevalence of anemia in adolescents aged 15 to 19 years [1], but no data are available examining the relationship between anemia status and folate status. A narrative review by Jack [13] suggested that micronutrient (folate and vitamin B_{12}) deficiencies may be prevalent irrespective of anemia status. The secondary aim of the study was to report the prevalence of anemia and test the hypothesis that nonanemic tribal adolescents aged 10 to 17 years may be folate deficient.

Methods

Characteristics of participants

This cross-sectional research was part of a longitudinal project entitled "Efficacy of Iron Biofortified Pearl Millet in Improving the Iron Status of Adolescents in India" conducted from August 2011 to April 2012 by the Department of Food Science and Nutrition, S.N.D.T. Women's University, Mumbai, India, in collaboration with Cornell University, USA, and HarvestPlus, USA. The present study was conducted in March 2012 in the economically disadvantaged tribal district (Sangamner Taluka, Ahmednagar District) of Maharashtra. Ethical clearance was obtained from the Inter Systems Bio-Medical Ethics Committee, Mumbai. Subjects were excluded if they were not between 10 and 17 years of age, were consuming multivitamin supplements, had physical disabilities, were medically diagnosed with chronic malabsorption issues (e.g., inflammatory bowel disorders) or health disorders (e.g., diabetes), or were severely undernourished (≤ –3 SD BMI z-scores) [14]. The children were residents of one of three selected boarding schools. The schools were sampled based on convenience. Written approval was sought from the school heads before commencing the study. During school hours, the homeroom teacher, accompanied by the research assistant, provided information about the study to the attending students. Students willing to participate were requested to submit the written informed consent form approved by their parents or guardians. Initially 262 students agreed to participate in the study. However, on the dates designated for data collection, taking blood samples, and recording sociodemographic information, a total of 224 students were present, and 204 students were present to provide dietary data. In summary, 224 tribal adolescents aged between 10 and 17 years participated.

Sociodemographic characteristics

A trained research assistant recorded the age and sex of the participants. Heights and weights were measured three times and averaged to assess whether the participant met the inclusion criteria (> –3 SD BMI z-scores) [14]. Weight was measured with a digital weighing scale (Equinox model EB6171) and recorded to the nearest 0.1 kg; height was measured against a vertical wall with a fiberglass measuring tape (Shenzhen Weiye glass-fiber measuring tape model B-0020) calibrated against a stadiometer and recorded to the nearest 0.1 cm. Weight was measured with the subject wearing light clothing without shoes, and height with the subject wearing no hair accessories or shoes.

Dietary assessment

Dietary data were collected every month as part of the longitudinal study conducted from August 2011 to April 2012. For the present study, the dietary data collected at the time of blood collection in March 2012 were used. Dietary data were collected by 13 research assistants who were trained for 15 days prior to the study. First, a 24-hour weighing method was conducted followed by a single multiple-pass 24-hour dietary recall. The multiple-pass 24-hour dietary recall was then validated against the 24-hour weighing method.

In the first step of the 24-hour weighing method, weighed food records were obtained 15 days prior to the beginning of the study in August 2011. Each research assistant was provided with two standardized and well-calibrated digital weighing scales (1-kg capacity, Eagle make, model no. EL01200; 7-kg capacity, Metro make, model no. SF-400), which recorded weights to the nearest 1 g. A standardized measuring tape (Shenzhen Weiye glass-fiber measuring tape model B-0020) was used to record the length, thickness, and diameter of food items to the nearest millimeter. Lastly, a set of calibrated pans, standardized glasses, cups, serving spoons, ladles, teaspoons, and serving dishes was provided. Data collection by the weighing method was conducted at two levels: the entire hostel level and the individual level.

Hostel level

In all three hostels, a cyclic menu was used, consisting of three standardized, uniform meals (breakfast, lunch, and dinner) in a day. The menus were monotonous, consisting of pearl millet flat bread, rice, pulses, less than 30 g of vegetables, and no fruits. For each recipe, all the raw ingredients used for the entire hostel were first weighed, and the volume was measured followed by measurement of the cooked yields in terms of weight as well as volume, numbers, and size/dimensions, including diameter, thickness, and length, wherever applicable, using standardized measuring equipment. Since the participants' diets were predominantly millet-based (pearl millet flat bread [*bhakri*]), the preparation of bhakri was monitored by research assistants specifically trained for bhakri assessment (i.e., recording the method of bhakri preparation and intake). The assistants periodically (every third day) weighed and recorded the flour used for bhakri preparation, and three randomly selected bhakris were weighed each day and their length, thickness, and diameter were measured in order to estimate actual intakes by the participants.

Individual level

The research assistant followed a randomly selected subsample of the participants ($n = 40$) over a 24-hour period. All foods and beverages consumed by the participants were weighed and/or measured using the calibrated digital weighing scales and standardized equipment.

In the single multiple-pass 24-hour dietary recall (second step), each participant was asked to recall all food items and beverages consumed on the previous day from the time he or she woke up in the morning to the last food item or beverage consumed at night. The time of consumption of each item was noted. Thereafter, for each item, the amount consumed was recorded in standard measures. Portion sizes were quantified using standardized food models and actual food items. The intake of *bhakri* was monitored daily by the specially trained research assistants by recording the number of *bhakris* consumed (to the nearest 0.25 unit) by each participant. Although a multiple-pass single 24-hour dietary recall conducted at the time of blood collection (March 2012) was used for the present study, it is important to note that the coefficient of variation) observed for specific nutrients (energy 2.2%, protein 2.4%, carbohydrate 2.2%, fat 2.9%, and folate 3.3%) was low for all time points in the longitudinal data (August 2011 to April 2012), as dietary data were collected every month. This indicated the monotonous and standardized nature of the diets.

Standardization of all food items (third step)

The data obtained from the 24-hour weighing method at the hostel level were cross-checked by preparing four portions of all recipes served to the participants during the entire study period in the nutrition laboratory of the Food and Nutrition Department at S.N.D.T Women's University. The yields of the prepared recipes were measured with standardized equipment. The prepared recipes were also analyzed for specific nutrients (energy, carbohydrate, protein, fat, and folate), and compared with the nutrient intakes obtained from the multiple-pass 24-hour dietary recall. A strong coefficient of correlation (r) was observed between both dietary methods for the selected nutrients ($r = 0.70$ for energy, 0.76 for protein, 0.65 for carbohydrate, 0.72 for fat, and 0.79 for folate). Therefore, for the present study, the single multiple-pass 24-hour dietary recall method could be considered valid.

CS Dietary software (version 1.11, Serpro S.A & HarvestPlus) was used to calculate nutrient intakes. The nutritive values of 479 raw foods given by the National Institute of Nutrition, Hyderabad, India, were entered [15]. Since these values are mainly for raw food items, a database for all the cooked foods was created for 105 standardized preparations that were commonly consumed. The software accounted for nutrient losses during cooking and processing. Intakes of total energy (kilocalories), carbohydrate (grams), protein (grams), fat (grams), and folate (micrograms) were calculated daily.

Supplement intake

Although consumption of multivitamin or mineral supplements was considered an exclusion criterion, the participants prior to data collection (blood serum and diet) were asked about any form of supplement usage. None of the participants reported consumption of nutritional supplements, and they had access to only three standardized meals per day provided by the school hostels.

Blood analysis

RBC folate was measured at Hinduja Hospital, Mumbai. using the Dual Count Solid Phase No Boil radioimmunoassay (Siemens Medical Solutions Diagnostics), which has been used in previous research [11] and has been shown to be comparable to the immunofluorescence method [16] and automated immunoenzymatic assay [17]. Fasting blood (7 mL) was collected by a trained phlebotomist from the antecubital vein into a single heparinized vacutainer tube (Beckman Dickinson). The red blood cells were separated from the plasma by centrifugation, stabilized with 1% ascorbic acid in a vacutainer, incubated for 60 minutes at room temperature, and frozen at −20°C. The radioactive iodine (I^{125}) count in the precipitate was measured with a Perkin Elmer automatic gamma counter, and folate concentrations were read from the calibration curve. Quality control was carried out using a number of tests involving lyophilized protein-based controls (control 1, 2.6 to 3.8 ng/mL; control 2, 6.9 to 9.3 ng/mL; control 3, 10.9 to 14.1 ng/mL; tracer reagent, radioactive I^{125}-labeled folic acid) with folate concentrations in the deficient range.

Hemoglobin was measured with the HemoCue Hb 201^{+} (A Quest Diagnostic Company), which has been shown to be comparable to the cyanmethemoglobin method and the automated Sysmex KX21N Hematology Analyzer [18]. Whole blood was analyzed for hemoglobin within 6 hours. The HemoCue Hb 201 consists of a single-use, disposable microcuvette that contains reagents in a dry form that convert hemoglobin into methemoglobinazide. Hemoglobin content is determined by a portable photometer, which measures the absorbance of methemoglobinazide at 570 and 880 nm to ensure automatic compensation for turbidity.

Statistical analysis

Logarithmic transformations were conducted to normalize the distribution of folate status, with RBC folate (nmol/L) reported as geometric mean (95% CI). Folate intake (μg/day) and anemia status (g/L hemoglobin) followed the normal distribution and are reported as mean ± SD. Median (25th, 75th interquartile range [IQR]) values are reported for all these variables. Folate status was categorized according to the World Health Organization (WHO) [19] recommendations as RBC folate deficiency levels < 340 nmol/L (< 151 ng/mL). Folate intakes were categorized according to the Recommended Dietary Allowances (RDAs) for folate by the Indian Council of Medical Research (ICMR) [20]: >140, > 150, and > 200 μg/day for the age groups 10 to 12, 13 to 15, and 16 to 17 years, respectively. The WHO cutoff points for nonanemia are ≥ 115 g/L hemoglobin for children aged 5 to 11 years, ≥ 120 g/L for children aged 12 to 14 years, ≥130 g/L for boys aged ≥ 15 years, and ≥ 120 g/L for girls aged ≥ 15 years. For mild anemia, the cutoff points are 110 to 114 g/L hemoglobin for children aged 5 to 11 years, 110 to 119 g/L for children aged 12 to 14 years, 110 to 129 g/L for boys aged ≥ 15 years, and ≥ 110 to 119 g/L for girls aged ≥ 15 years [21]. For all age groups and both sexes, moderate and severe anemia are defined as hemoglobin levels of 80 to 109 g/L and < 80 g/L, respectively [21]. For each adolescent, according to his or her age and sex, the anemia status (g/L hemoglobin) was coded as nonanemic, mildly anemic, moderately anemic, or severely anemic based on the WHO [21] age- and sex-specific categories. The participants were classified into age groups (10 to 12, 13 to 15, and 16 to 17 years) according to the categories given by the ICMR [20] to establish RDAs for adolescents. RBC folate status, folate intake, and anemia status are reported by sex and age group. ANOVA/independent-samples *t*-test and Pearson's chi-squared test were used for continuous and categorical variables, as appropriate. Pearson's chi-square test was used to examine the association between adequacy of folate intake and RBC folate deficiency and between anemia status and RBC folate deficiency across age groups and sexes. A p-value < .05 was considered to indicate statistical significance. The analyses were performed with SPSS, version 21.

Ethical approval

The study was approved by the Inter Systems BioMedical Ethics Committee, Mumbai.

Results

Characteristics of the participants are presented in **table 1**. The highest proportion of the participants were 13 to 15 years of age (68.3%, $n = 153$), followed by those aged 16 to 17 (18.3%, $n = 41$) and 10 to 12 years (13.4%, $n = 30$). Forty-one percent of the participants were girls.

Overall, there was no significant difference in mean RBC folate concentration between girls (152.0 nmol/L; 95% CI, 133.0 to 173.7) and boys (164.2 nmol/L; 95% CI, 145.6 to 185.1; $F(1) = 0.71$, $p = .39$). RBC folate status by age and sex is reported in **table 2**. Among children aged 16 to 17 years, girls were 3.8 times more likely than boys to be deficient in RBC folate (< 340 nmol/L) (OR = 0.27; 95% CI, 0.07 to 1.02; $p = .04$).

Overall, mean ± SD folate intake was significantly lower in girls than in boys (139.4 ± 34.5 vs. 173.8 ± 45.5 μg/day; $t(202) = 5.8$, $p < .001$). **Table 2** highlights folate intakes of the participants by age category and sex. For the age group 13 to 15 years, girls had significantly lower mean folate intake than boys ($t(139) = 5.9$,

TABLE 1. Summary of participants' characteristics (n = 224)

Characteristic	Mean ± SD	Median (25th–75th interquartile range)
Age (yr)	14.0 ± 1.3	14.0 (13.0, 15.0)
RBC folate status (nmol/L)	360.2 (329.7–393.6)[a]	365.3 (254.3, 551.3)
Folate intake (µg/day)	159.9 ± 44.7	152.6 (131.7, 154.8)
Hemoglobin status (g/L)	125.4 ± 13.0	125.0 (117.3, 134.0)
Energy (kcal/day)	1938.4 ± 391.4	1946.4 (1696.5, 2168.0)
Carbohydrate (g/day)	330.6 ± 71.5	334.3 (277.1, 367.1)
Protein (g/day)	59.7 ± 23.4	54.9 (45.6, 69.1)
Fat (g/day)	45.8 ± 12.8	43.3 (36.9, 53.4)
Cell morphology	%	*n*
Normocytic	82.1	184
Normochromic	82.1	184
Mild microcytosis	11.6	26
Moderate microcytosis	0.9	2
Mild hypochromasia	14.3	32
Moderate hypochromasia	1.8	4
Mild macrocytosis	0.9	2
Moderate macrocytosis	0.4	1

a. Geometric mean (95% CI) is reported.

TABLE 2. RBC folate (n = 224), folate intake (n = 204), and hemoglobin status (n = 224) of participants by age and sex

Measurement	Boys	Girls	*p*
RBC folate status (nmol/L)—mean (95% CI)[a]			
10–12 yr	447.4 (306.9–652.2)	365.7 (222.2–601.7)	.49
13–15 yr	366.5 (316.2–424.8)	353.5 (301.3–414.7)	.75
16–17 yr	346.9 (265.8–452.7)	291.3 (223.3–379.9)	.38
RBC folate deficiency (< 340 nmol/L)—no. (%)[b]			
10–12 yr	7 (41.2)	6 (46.2)	.78
13–15 yr	38 (43.2)	28 (43.1)	.99
16–17 yr	9 (34.6)	10 (66.7)	.04
Folate intake (µg/day)—mean ± SD[c]			
10–12 yr	171.0 ± 51.4	159.7 ± 44.6	.56
13–15 yr	174.4 ± 46.7	133.1 ± 31.2	< .001
16–17 yr	172.3 ± 39.4	151.3 ± 30.6	.13
Inadequate folate intake—no. (%)[b]			
10–12 yr (< 140 µg/day)	5 (29.4)	7 (53.8)	.11
13–15 yr (< 150 µg/day)	34 (38.6)	51 (78.5)	< .001
16–17 yr (< 200 µg/day)	20 (76.9)	15 (100.0)	.04
Hemoglobin status (g/L)—mean ± SD[c]			
10–12 yr	126.1 ± 11.8	120.7 ± 10.4	.20
13–15 yr	129.8 ± 11.1	118.0 ± 13.0	< .001
16–17 yr	130.1 ± 11.3	127.5 ± 15.3	.53

a. ANOVA.
b. Pearson's chi-square.
c. Independent-samples *t*-test.

$p < .001$) and were 5.8 times (OR = 0.17; 95% CI, 0.08 to 0.36; $p < .001$) more likely to have an inadequate intake of folate (< 150 µg/day). For the age group 16 to 17 years, all girls and 76.9% of boys did not meet their daily RDA of folate intake (200 µg/day) ($p = .04$) (**table 1**).

Overall, girls had significantly lower mean hemoglobin concentrations than boys (119.9 ± 13.4 vs. 129.4 ± 11.3 g/L; $t(222) = 5.7$; $p < .001$). Mean ± SD hemoglobin concentrations by age and sex are reported in **table 2**. Girls aged 13 to 15 years had significantly lower mean hemoglobin levels than boys ($p < .001$). Anemia status by age and sex is reported in **table 3**. Overall, the greatest proportion (63.8%) of the sample were nonanemic; 27.7%, 7.6%, and 0.9% were mildly, moderately, and severely anemic, respectively. With increase in age, the proportion of nonanemic boys decreased; in contrast, the proportion of nonanemic girls increased with age.

The associations between adequacy of folate intake and RBC folate deficiency (< 340 nmol/L), and between anemia status and RBC folate deficiency across age groups and sex were nonsignificant (**table 4**). For both sexes, the linear, nonsignificant association between dietary folate and RBC folate status is represented in **figures 1** and **2**.

Discussion

The study aimed to examine the prevalence of folate deficiency, report the adequacy of folate intake, and study the association between folate intake and RBC folate status in adolescents aged 10 to 17 years. The secondary aim of the study was to investigate the association between anemia and RBC folate status. In brief, the principal findings showed that folate deficiency was widely prevalent in the study sample. Among both boys and girls aged 10 to 12 and 13 to 15 years, almost half were folate deficient (RBC folate < 340 nmol/L). In the older age group (16 to 17 years), two-thirds of girls were folate deficient. In all age groups, a greater proportion of girls (at least 50%) than boys did not meet their RDA for folate. Nearly two-thirds of the adolescents were nonanemic. No significant associations were observed between folate intake and RBC folate

TABLE 3. Anemia status of adolescents by sex and age ($n = 224$)

Sex and age group (yr)	Anemia status—no. (%)			
	Nonanemic	Mildly anemic	Moderately anemic	Severely anemic
Boys				
10–12	13 (76.5)	—	4 (23.5)	—
13–15	65 (73.9)	20 (22.7)	3 (3.4)	—
16–17	12 (46.2)	14 (53.8)	—	—
Total	90 (68.7)	34 (26.0)	7 (5.3)	0 (0)
Girls				
10–12	8 (61.5)	3 (23.1)	2 (15.4)	—
13–15	33 (50.8)	22 (33.8)	8 (12.3)	2 (3.1)
16–17	12 (80.0)	3 (20.0)	—	—
Total	53 (57.0)	28 (30.1)	10 (10.8)	2 (2.2)

TABLE 4. Association between folate intake and RBC folate deficiency (< 340 nmol/L) and between anemia status and RBC folate deficiency by sex and age (boys, $n = 122$; girls, $n = 113$)

RBC folate-deficient adolescents by sex and age group (yr)	Folate intake—no. (%)			Anemia status—no. (%)		
	Inadequate[a]	Adequate	p^b	Nonanemic	Anemic	p^b
Boys						
10–12	3 (42.9)	4 (57.1)	.31	7 (100.0)	0 (0.0)	.06
13–15	17 (44.7)	21 (55.3)	.31	26 (68.4)	12 (31.6)	.31
16–17	6 (66.7)	3 (33.3)	.33	3 (33.3)	6 (66.7)	.34
Girls						
10–12	4 (66.7)	2 (33.3)	.39	2 (33.3)	4 (66.7)	.05
13–15	22 (78.6)	6 (21.4)	.99	13 (46.4)	15 (53.6)	.54
16–17	10 (100.0)	0 (0.0)	—	8 (80.0)	2 (20.0)	1.00

a. Inadequate folate intake: 10 to 12 years, < 140 µg/day; 13 to 15 years, < 150 µg/day; 16 to 17 years, < 200 µg/day.
b. Pearson's chi-square test.

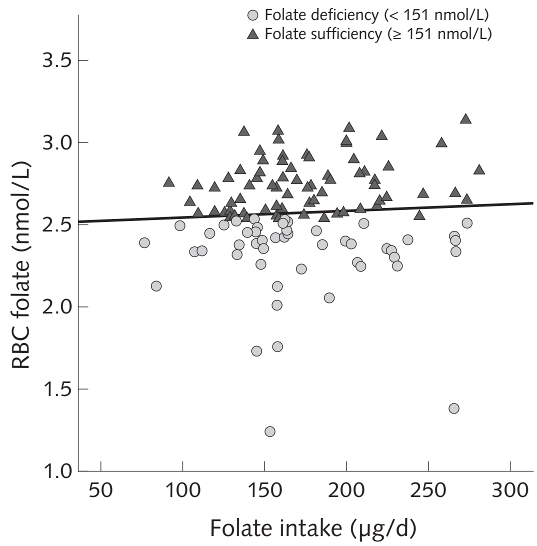

FIG. 1. Lack of significant association between folate intake and red blood cell (RBC) folate status for boys (n = 131, r = 0.06, p = .48)

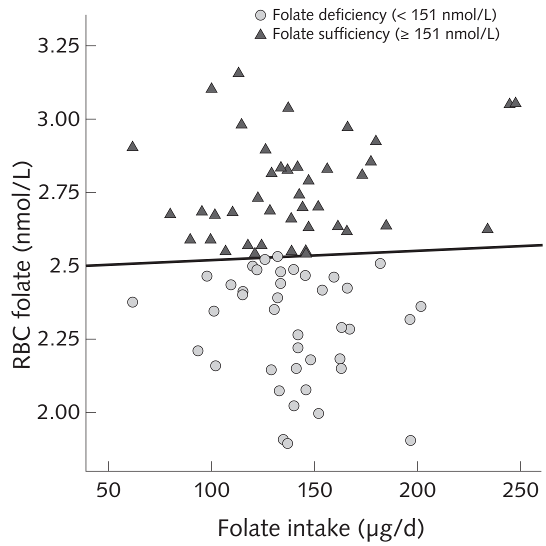

FIG. 2. Lack of significant association between folate intake and red blood cell (RBC) folate status for girls (n = 82, r = 0.04, p = .76)

deficiency or between anemia status and RBC folate deficiency.

Research has predominantly examined folate status using serum folate [8, 22–25]. Serum folate levels reflect recent folate intake, whereas RBC folate is a better indicator of long-term intake, because it has a half-life of approximately 100 days and may not easily be manipulated by short-term dietary changes [6, 26]. There are limited studies reporting RBC folate levels for adolescents. The mean RBC folate levels for 890 Taiwanese children [6] were markedly higher than those of Indian children in the present study (645 vs. 181 nmol/L for ages 10 to 12 years). Similarly, the median (721 to 518 vs. 365 nmol/L) and mean (543 vs. 360 nmol/L) RBC folate concentrations for European (n = 1,051, 12.5 to 17.5 years) [7], British (n = 485, 11 to 18 years) [5], and American (n = 4,050, 12 to 19 years) [27] adolescents were distinctly higher than the RBC folate values noted for the tribal Indian adolescents from a comparable age group (10 to 17 years).

Several factors may explain the lower mean RBC folate levels of the tribal adolescents compared with those reported in the wider literature. Previous studies were carried out in affluent nations; in contrast, our study was conducted in tribal India. None of the tribal Indian adolescents consumed folate-fortified products or nutritional supplements. In contrast, mandatory and voluntary (e.g., fortified breakfast cereals) folate fortification programs are operated in the United States [27] and the United Kingdom [5], respectively (**table 4**). Consumption of nutritional supplements was reported among 9% of Taiwanese children [6] and 11% of European adolescents [7]. However, RBC folate status was not reported separately for adolescents of the comparable age group (10 to 17 years) consuming vs. not consuming nutritional supplements. Therefore, RBC folate status as per supplement consumption vs non-consumption was not compared.

Furthermore, in contrast to the predominantly cereal-based diets consumed by the studied Indian adolescents (pearl millet flat bread, pulses, less than 30 g of vegetables [potatoes, gourds, occasionally leafy vegetables], and no fruits), Taiwanese diets [6] are rich in fruits and vegetables that are important sources of dietary folate [6]. Thus, these factors may have contributed to higher RBC folate concentrations observed in previous research compared with the present study.

Our findings showed that, in comparison with 890 Taiwanese children, the mean folate intake for boys (171 vs. 322 μg/day) and girls (159 vs. 287 μg/day) was lower for a similar age category (10 to 12 years) [6]. For a comparable age group (10 to 17 years), the mean folate intake of Indian boys (173 vs. 331 μg/day) and girls (139 vs. 227 μg/day) was lower than that of American adolescents (n = 3,121, 12 to 19 years) during the prefortification period from 1988 to 1994 [28]. In contrast, for a similar age range (10 to 17 years) the mean folate intake of tribal Indian boys (162 vs. 173 μg/day) and girls (133 vs. 139 μg/day) was higher than that of adolescents from a low socioeconomic background in Brazil (10 to 19 years, n = 722), a developing nation similar to India [4] (**table 4**). Similarly, the mean folate intakes observed in the present study were considerably higher compared with the national Indian data for all age groups and both sexes (10 to 12 years, 39 to 41 μg/day; 13 to 15 years, 43 to 47 μg/day; 16 to 17 years, 47 to 53 μg/day) [3]. The National Nutrition Monitoring Bureau [3] provides the latest and the only data on the folate intakes of Indians at a population level. The data examine the rural but not the tribal populations from nine states across India. Both the national data (rural adolescents) [3] and the present study (tribal adolescents) reflect intakes of economically deprived sections; however, the differences between the study findings could be partly due to the populations studied and the accuracy of the methods used. The national data [3] estimated folate levels (μg/day) from foods consumed in home settings recorded using a 24-hour dietary recall; therefore, the findings will show more dietary variation and also could be subjected to greater measurement (recall) bias. In contrast, the present study had a relatively controlled environment, since the school hostels ensured three meals from standardized menus. Therefore, the quantity and quality of the food and the number of meals available in rural homes versus school hostels could partly explain the higher mean folate intake by tribal adolescents in the present study.

The results showed that the mean folate intake of girls was significantly lower (by 20 percentage points) than that of boys. Similarly, in previous studies, girls had a lower folate intake than boys [3, 6, 28]; this difference reached statistical significance in the study by Vitolo et al. [4]. In light of the standardized menus served to all participants, significant differences in physiological capacities (amount of food consumed) between boys (2088.2 kcal) and girls (1713.6 kcal) may partly account for the lower folate intake in girls. With respect to adequacy of folate intake, the US dietary guidelines [29] recommend that females consume a minimum of 400 μg of folate per day. In India, it would be advisable to commence consuming the recommended 400 μg/day of folate during the adolescent years, as the median age of Indian women at the birth of their first child is 19 years [1]. However, none of the tribal adolescent girls in our study met the guidelines (the maximum intake was 247 μg/day).

Finally, no association was observed between folate intake and RBC folate status. This tendency is consistent with previous cross-sectional research [6]. In the present study, folate intake may reflect current and long-term dietary patterns, as all participants were served standardized and uniform meals by the school hostels. Therefore, folate intake is suggested to be constant, only affected by the amount of food consumed, which varied by sex. This low disparity in folate intake may account for minimal variance in RBC folate status.

In comparison with the Indian national data [1], a lower proportion of girls aged 15 years or more in the present study were diagnosed with anemia (hemoglobin < 120 g/L) (38.5% vs. 55.8%). In contrast, a higher proportion of boys aged 15 years or more were anemic (hemoglobin < 130 g/L) in comparison with the national data (46.4% vs 30.2%) [1]. The results showed that girls aged 13 to 15 years had significantly lower mean hemoglobin levels than boys; this may partly reflect blood loss during the onset of menstruation, which occurs on average at the age of 12 or 13 years [30]. Secondary findings also revealed that 60.2% of all adolescents who were folate deficient were nonanemic. Therefore, the hypothesis was accepted that nonanemic adolescents could still be folate deficient. This emphasizes that micronutrient deficiencies need due attention at the national level. In April 2012, the Government of India announced the Weekly Iron (100 mg) and Folic Acid (500 μg) Supplementation Programme (WIFS) for urban and rural adolescents (aged 10 to 19 years) for 52 weeks annually [31]. However, implementation of the project throughout the nation is rather slow, and the inclusion of tribal adolescents is unclear.

The main strength of our study is that it is the first to investigate folate status, folate intake, and the associations between folate intake and folate deficiency and between anemia status and folate deficiency in nonaffluent tribal Indian adolescents. The findings are also strengthened by the use of validated procedures to measure folate and hemoglobin status and record dietary intake data. Unlike other published studies, our study was conducted in a relatively controlled setting (school hostels) where meals were prepared from standardized menus. Therefore, comparison of the present study findings with those of other studies should be done with care. The cross-sectional design of the study cannot examine changes over time. Furthermore, the convenience sampling technique limits the findings to tribal adolescents residing in school hostels in Ahmednagar District. The relatively small sample size limited the amount of analysis that could be done on subgroups of participants, and therefore the findings need to be replicated in studies with larger samples. Considerable internal validity of the dietary intake data was assured because of the systematic data collection approach (i.e., validation of the multiple-pass 24-hour dietary recall against the weighing method). Furthermore, all research assistants were sufficiently trained (15 days) to consistently and accurately record the dietary data. However, errors secondary to multiple researchers' bias cannot be ignored. In addition, due to pragmatic concerns (time, funds), only a single multiple-pass 24-hour dietary recall was conducted. However, it is important to consider that the participants' diets were monotonous, as previously discussed. Folate intakes were categorized according to the age- and sex-specific RDAs suggested by the ICMR [20]. In comparison with the RDA, the Estimated Average Requirement (EAR) represents the preferred dietary reference value for nutrient intakes [32]. The RDA is two standard deviations above the EAR and therefore may overrepresent folate intake inadequacy. Presently, in India the ICMR only provides the RDA for folate intake for Indians, which was used to study inadequacy of folate intake. In addition, the EARs suggested by the

US dietary guidelines [33] for comparable age groups are higher than the RDAs recommended for Indians by the ICMR [20], which further emphasizes the folate-deficient diets of the participants.

An important take-home message from the study would be to consider potential strategies to address the issue of folate deficiency and dietary folate inadequacy among economically deprived Indian adolescents. In the United States, the mandatory folic acid fortification program resulted in an increase in RBC folate status and folic acid intake by 33 and 25 percentage points, respectively, from the prefortification period (1988 to 1994) [28] to the postfortification period (2003 to 2006) [34]. A 14-month, randomized, controlled study examining a micronutrient-rich-beverage in 869 affluent Indian children 6 to 18 years of age observed a significant increase in mean RBC folate status from baseline (300 nmol/L) to the end of the trial (600 nmol/L) [11]. In addition to the existing measures implemented in India (WIFS Programme) and overseas (mandatory folate fortification in the United States), novel approaches are required that are not only economically feasible but also culturally acceptable to improve folate status and intake, especially among tribal Indian adolescents. Increasing awareness of indigenous fruits and leafy vegetables, which are abundantly available in the tribal districts, may be a pragmatic strategy to improve folate intake. Finally, cell morphology indicative of deficiencies of iron (e.g., microcytosis, hypochromasia) and vitamin B_{12} (macrocytosis) were examined, but actual blood parameters were not, due to insufficient serum samples and funding. Future research can examine folate status in relation to specific biochemical parameters for vitamin B_{12} (e.g., serum holotranscobalamin level) and iron (serum ferritin) status, as deficiencies of these nutrients can lead to abnormal hemopoiesis and anemia status [20].

Conclusions

Folate deficiency was widespread among tribal Indian adolescents aged 10 to 17 years. In addition, girls had poorer folate intakes than boys. These findings are of concern because insufficiency of folate may have detrimental health consequences (e.g., cardiovascular diseases) for the individual that may be carried forward into adulthood. Therefore, there is an urgent need to develop strategies (e.g., increase dietary diversity using locally available fruits and leafy vegetables) that may address the issue of folate insufficiency in this potentially vulnerable group.

Conflicts of interest

All authors declare that they have no conflict of interest.

Authors' contributions

Rati Jani critiqued the published literature, performed the data analyses, and drafted the manuscript. Nisha Salian, Shobha A. Udipi, and Padmini S. Ghugre managed the biochemical, dietary, and anthropometric assessments. Shobha A. Udipi, Padmini S. Ghugre, Jere Haas, and Erick Boy served as principal investigators responsible for the design and implementation of the project. Shobha A. Udipi, Padmini S. Ghugre, and Jere Haas also provided their expert feedback in revising the manuscript. Neha Lohia contributed to the preliminary data analyses. All authors gave their final approval for submission.

Acknowledgments

We acknowledge the contributions of Anil Udawant, field coordinator, in managing the collection of blood samples and Ashwini Salvi and Aparna Thorat for organizing the fieldwork and data collection. We thank the Ahmednagar Zilla Maratha Vidya Prasarak Samaj, which receives aid for tribal welfare (free accommodation, education, and food) from the Government of Maharashtra, for permitting us to conduct the study in their school hostels. We are thankful to all the students for their participation. The study was funded by HarvestPlus, International Food Policy Research Institute, USA.

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Acceptability and utility of an innovative feeding toolkit to improve maternal and child dietary practices in Bihar, India

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Abstract

Background. *Dietary practices in India often fail to provide adequate nutrition during the first 1,000 days of life.*

Objective. *To explore the acceptability and utility of a low-cost and simple-to-use feeding toolkit consisting of a bowl with marks to indicate meal volume and frequency, a slotted spoon, and an illustrated counseling card to cue optimal dietary practices during the first 1,000 days.*

Methods. *In Samastipur District, Bihar, India, we conducted 16 focus group discussions and 8 key informant interviews to determine community acceptability and obtain feedback on design and delivery of the feeding toolkit. We conducted 14 days of user testing with 20 pregnant women, 20 breastfeeding women 0 to 6 months postpartum, and 20 mothers with infants 6 to 18 months of age.*

Results. *The toolkit, which is made of plastic, was well accepted by the community, although the communities recommended manufacturing the bowl and spoon in steel. The proportion of pregnant and breastfeeding women taking an extra portion of food per day increased from 0% to 100%, and the number of meals taken per day increased from two or three to three or four. For children 6 to 18 months of age, meal frequency, quantity of food consumed during meals, and thickness of the foods increased for all age groups. Children 6 to 8 months of age who had not yet initiated complementary feeding all initiated complementary feeding during the testing period.*

Conclusions. *Simple feeding tools are culturally acceptable and can be appropriately used by families in Bihar, India, to improve dietary practices during the first 1,000 days of life. Research is needed to assess whether the tools promote dietary and nutritional improvements over and above counseling alone.*

Key words: Acceptability, cues to action, dietary practices, feeding tools, maternal and child nutrition

Introduction

In India, over 50% of children under 3 years of age are stunted and 33% are wasted [1]. Stunting and wasting begin early in infancy; recent research found that at 5 months of age approximately 30% of Indian children were wasted and 20% were stunted [2]. Poor nutrition in pregnancy, including low gestational weight gain, is common in India and is likely a major determinant of low birthweight and the initiation of a suboptimal postnatal growth trajectory [3, 4]. Low uptake of exclusive breastfeeding, compounded by inadequate complementary feeding practices from 6 months onward, further exacerbates growth-faltering and other developmental delays in early childhood [2]. Supporting optimal nutrition throughout the first 1,000 days, from conception through 2 years, optimizes both maternal health and child growth and development [5].

Sustained behavior change is foundational to nutrition improvement. However, recent systematic reviews of educational programs designed to improve nutrition in pregnancy, exclusive breastfeeding, and complementary feeding practices found that although practices can be improved, the degree of improvement is often small [6–11]. Programmatic and research experiences highlight that in many cases families vastly underestimate

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how much and how often to feed very young children, how thick porridge should be to ensure optimal energy density, or how much extra food is needed during pregnancy and breastfeeding. As a result the quantity, quality, and number of meals during these critical periods often remain below recommendations [11]. The Manoff group developed a child feeding bowl that uses marks to indicate meal volume and frequency. This bowl was found to be acceptable in trials of improved practices in Latin America [12], but effects on meal volume were not reported. Furthermore, the Manoff bowl does not cue other aspects of optimal Infant and Young Child Feeding (IYCF), such as meal frequency or diversity. It does not include a tool for cueing thickness of meals (i.e., the slotted spoon), nor does it cue adequate maternal nutrition.

To address this gap in the literature, our team developed a simple, easy-to-use feeding toolkit consisting of a bowl with marks to indicate meal volume and frequency, a slotted spoon, and an illustrated counseling card for use during the entire 1,000-day period. The symbols and lines on the bowl serve as cues to action for optimal meal amounts and frequencies, whereas the slotted spoon cues adequate thickness of food. The accompanying counseling card supports optimal food consumption practices with pictorial instructions on the use of the bowl and spoon, information on dietary diversity (with pictures showing a variety of animal-source foods, fruits, staples, and vegetables), and visual cues for hygienic food preparation. Symbols on the bowl and counseling messages on the card cue pregnant women to take their normal diet plus one additional serving of nutritious food from the bowl “for the baby.” The mother continues to use the bowl in the same way during the first 6 months postpartum to support her during the period of exclusive breastfeeding. The mother then transitions the bowl to the infants at 6 months to facilitate timely introduction and age-appropriate meal frequency and quantity. As the child ages, the mother gradually increases the amount and frequency of feeds, as indicated by the lines and symbols on the bowl. The slotted spoon allows the mother to test the consistency of the infant’s meal to ensure it is of adequate thickness. For example, if porridge flows through the slots, the mother knows to add more flour to thicken the porridge.

From May to August 2013, our team explored dietary knowledge, attitudes, and practices during the 1,000-day window and the acceptability and feasibility of the feeding toolkit to influence practices during this period in Samastipur District, Bihar, India. This research gathered feedback and recommendations on the design of the bowl and spoon, optimal delivery platforms, and appropriate messaging and counseling materials, as well as user perceptions, external influencers of uptake, and potential barriers to and facilitators of implementation.

Methods

Development of the feeding toolkit

The bowl, spoon, and pictorial counseling card were developed to serve as a simple toolkit that cues the appropriate volume, consistency, and diversity of food and the number of meals to consume per day to support each stage of the 1,000-day period. The symbols and lines on the bowl indicate optimal meal frequencies and amounts, respectively, for mothers and children during the first 1,000 days of life (pregnancy, breastfeeding, and the period of complementary feeding from 6 to 24 months). The slotted spoon cued adequate thickness of food; for example, if a child’s porridge was insufficiently thick it would pass through the slots, cueing mothers to add more flour or oil to thicken the porridge. The counseling card supported optimal food consumption practices with pictorial instructions on the use of the bowl and spoon during the different life stages, appropriate breastfeeding, information on dietary diversity (i.e., pictures showing a variety of animal source foods, fruits, staples and vegetables), and visual cues for hygienic food preparation. The parameters set out by Dewey and Brown [13] were used to develop the volume marks on the bowl. Bowl and spoon prototypes were rendered using SolidWorks software and printed on a Stratasys Dimension 3D printer. Multiple sizes for spoon slots were tested using locally relevant complementary foods of varying consistency, including rice porridge, maize porridge, and millet porridge. Refinements to the shape and design of the bowl and spoon as well as counseling materials were made based on input from technical experts in the field of behavior change and maternal and child health and nutrition at CARE (Atlanta, GA, USA), CARE India (Patna, Bihar, India), and Emory University (Atlanta, GA, USA). The final prototypes used in field testing in Bihar were produced with food-grade polypropylene by a protomold injection molding process by Proto Labs (Maple Plain, MN, USA). Images of the toolkit are available from the authors upon request.

Design, study setting, and recruitment of participants

Formative qualitative research was conducted in collaboration with the larger Integrated Family Health Initiative (IFHI) implemented by CARE India in Bihar in one urban and one rural community in Samastipur District, Bihar. CARE staff served as gatekeepers and recruited frontline health workers and community members to participate in focus group discussions, in-depth interviews, and user testing. Participants were recruited from their homes, Anganwadi Centers that provide nutrition support to pregnant and lactating women and young children and early childhood development programs to local communities, health subcenters, and community spaces to provide diversity in social characteristics, including caste and religion.

Data collection

From May to August 2013, we conducted 16 focus group discussions, 8 key informant interviews, and user testing with 60 families. The focus group discussions included, on average, 10 participants and were held with each of the following stakeholder groups: pregnant women and women with children 0 to 2 years of age, mothers-in-law, husbands, community leaders, and frontline health workers (Accredited Social Health Activists [ASHAs] and Anganwadi Workers [AWWs]). Focus group discussions with mothers and pregnant women and mothers-in-law were stratified into two groups according to caste, with General and Other Backward Caste constituting one group and Scheduled Caste and Scheduled Tribe constituting the other group. Eight key informant interviews were conducted with local experts in maternal and child nutrition, including one CARE District Manager, two Child Development Project Officers, one District Project Officer, one Auxiliary Nurse Midwife, one physician, and two Lady Supervisors. The focus group discussions and interviews explored community beliefs about maternal and child nutrition and examined the initial reactions to the feeding bowl and spoon, acceptability, potential delivery platforms, and promotion strategies, as well as potential barriers to use.

In each community, we conducted user testing with 10 pregnant women, 10 breastfeeding women less than 6 months postpartum, and 10 women with children 6 to 24 months of age, for a total of 30 urban and 30 rural participants, using a modified Trial of Improved Practices (TIPS) approach [12]. The families were provided with the complete feeding toolkit (bowl, spoon, and counseling card) for a 14-day trial period. Data collection and counseling occurred in the home at three time points:

Enrollment/baseline. Semistructured interviews captured current dietary practices, explored expectations and potential problems with the toolkit, and captured basic household demographics. The research assistants then provided the mothers or caregivers (hereafter referred to collectively as “mothers”) with dietary counseling appropriate for their or their children’s needs, including detailed counseling on how to use the feeding toolkit for the relevant life stage (pregnancy, lactation, and complementary feeding).

Midline (day 7). The research assistants “checked in” with the participants and observed their use of the feeding toolkit. The mothers were interviewed about their experiences using the bowl and spoon and any problems experienced. The mothers were provided with one or two additional or reinforcing counseling messages based on needs emerging during the interview.

Endline (day 14). Interviews assessed dietary and feeding practices, use of the toolkit, acceptability, problems, and recommended modifications. Where feasible, study staff observed the use of the bowl and spoon for complementary feeding. Additional counseling was provided to reinforce mothers’ knowledge on how to use the toolkit for the other life stages. The toolkit was left with the family.

User testing was followed by a focus group discussion with five to eight participating mothers in a central location in each community (one urban and one rural). The focus group discussions expanded on users’ experiences with the feeding toolkit, acceptability, problems encountered, potential delivery platforms, and perceived benefits.

Data preparation and management

Detailed notes were taken during all focus group discussions, and the interviews were also voice-recorded with the participants’ consent. The notes and recordings were used to generate detailed summaries and verbatim transcripts that were translated from Hindi into English and deidentified. Each team of transcribers consisted of two research assistants. One research assistant transcribed the recording into Hindi, and the other reviewed the transcript against the recording and detailed summaries. Edits were made in Hindi, and the transcript was then sent to a translator who translated it into English. The English translation was verified against the Hindi transcripts and recording by a third team member who was fluent in English and Hindi.

These data were supplemented with the interviewer’s field notes, which provided information on the participants, the context of the interview, and the interviewer’s own reflections about the interview. A bilingual team member who was not involved in their development verified all summaries, transcripts, and translations against the recordings. The recordings were stored in a secure location. Once the transcripts, the detailed summaries, and their translations had been verified, the recordings were destroyed. The deidentified detailed summaries, transcripts, and other data were stored in password-protected computers.

Data analysis

Qualitative data were entered into MAXQDA software, version 11, coded, and analyzed using a thematic analysis approach. The first step in data analysis was to identify specific a priori codes for each of the topics that were presented by the facilitator or interviewer. Additional inductive codes were identified as they emerged from the discussions. The codes were used to develop themes that were used to create a set of matrices. Evaluation of salience was based on the frequency with which a specific theme was reported in each transcript and by examining the nature of the discussion about that topic in each interview and focus group discussion. Throughout the analytic process, we also made notes of representative quotes.

Ethical approval

The study protocol was approved by the Institutional Review Board of Emory University and an independent ethical review board in India (Futures Group). All participants provided oral consent to participate in the focus group discussions and interviews, and a written form that described the study and the components of the consent process (translated into Hindi) was given to the participants before their consent.

Results

The results are organized into three categories: community norms and current maternal and child nutrition practices, potential of the feeding toolkit to shift diet practices, and recommended design modifications and delivery platforms.

Community norms and current maternal and child nutrition practices

The barriers to adequate diets during pregnancy and breastfeeding varied by residence type (rural or urban) but not by caste or religion. For rural women, lack of affordability of additional food and a perception that current practices were sufficient emerged as the main barriers to consuming the recommended maternal diet. For urban women, concern over "becoming fat" was cited as the main reason for an inadequate diet. Interestingly, pregnant women in both urban and rural communities received counseling from their mothers-in-law to eat less animal-protein foods and not to consume extra food while pregnant because they would "become too heavy."

For breastfeeding women, there is a belief that *mansoor ka dal* (a traditional pulse dish) aids in the production of breastmilk. Mothers believe that once they eat this dish there is no need to eat more food. This belief was reiterated across residence types (urban and rural) and religion (Muslim and Hindu). With regard to child nutrition, initiation of complementary feeding in both urban and rural areas was based on the religious calendar and revolved around the date selected by the priest to give the first sweet to the child. Once this ritual is performed, then other foods can be introduced. Thus, timing of the initiation of complementary feeding may fall earlier or later than 6 months.

Provision of semisolid foods often begins around 9 months, although younger children are often given *dal ka paani* (watery pulses) and cow's and goat's milk in addition to breastmilk. It is a widely held belief that children should not be given animal-based proteins (eggs, meat, and fish) until at least 1½ years of age because their digestive system cannot handle animal proteins before that age. Mothers generally feed their children two or three times a day on average, regardless of age. The amount of food fed to children tends to slowly increase as the child grows and is based on the mother's discretion. Many community members, including mothers and mothers-in-law, cited a lack of certainty about the frequency of meals for young children and the amount of food to give. Few reported receiving counseling on how much to feed their child, and those who had received counseling described it as inadequate. The results from focus group discussions with the frontline workers highlighted their limited knowledge of maternal and child nutrition practices. The frontline workers also discussed their heavy workload, indicating it limited the counseling they could provide during home visits. As one frontline worker said:

> *The mothers I visit are many in my village. I have to visit them all to give them a lot of messages. This makes me very tired and less effective when I go to my later houses as I am very tired by that time.*

Mothers-in-law were considered by community members to be the most knowledgeable and experienced in regard to maternal and child diet and nutrition and as such have the greatest influence on these practices. As one rural pregnant woman stated:

> *My mother-in-law has all information and she is well experienced. She took care of my husband and so she is the one who advises me on what to eat and she will also tell me what to feed my child when I give birth. She is always right so I follow her advice.*

Potential of the feeding toolkit to shift dietary practices: Findings from trials of improved practices user testing

Use of the bowl and spoon by pregnant and breastfeeding mothers

At baseline, 18 of 20 pregnant women were eating two or three times per day and 2 were eating three or four times a day. None reported consuming extra food or an extra meal during their pregnancy. Similarly, breastfeeding mothers were eating two or three times per day, with none eating additional meals. Intake of animal-source foods was low, even among those describing themselves as nonvegetarians. ("Vegetarian" in this context refers to someone who consumes dairy products but not meat or eggs.) At baseline, all women were provided the feeding toolkit and counseled on using the bowl to consume an extra serving of food each day. Depending on their current practices, women were also counseled in regard to consumption of iron–folic acid supplements (only during pregnancy) and consumption of protein-rich foods.

By endline, all mothers reported using the bowl at least once a day, seven times a week. Some, but not all, women also reported using the spoon to check the consistency of their food. Pregnant women, but not breastfeeding women, reported less frequent use of the toolkit in the first 7 days. Some were not permitted by their mothers-in-law to use the toolkit because the mothers-in-law were not present during initial counseling and were wary of its benefits. Some pregnant women were hesitant to use the tools for fear that their morning sickness would intensify.

During the 14-day trial, most women reported increasing the quantity of food consumed at meals, meal frequency, and consumption of snacks, and pregnant women reported increasing their consumption of iron–folic acid (**table 1**).

Both pregnant and breastfeeding women perceived that the marks on the bowl and the slots in the spoon assisted them in determining the appropriate quantity and consistency of food. The mothers indicated that the pictorial counseling cards supported increases in frequency and quantity of meals and contributed to the consumption of snacks and increased diversity of food, especially animal-source foods. The women also reported that they felt stronger and healthier after the 14-day trial and indicated they could go about their duties without feeling weak as compared with when they were not using the bowl. Pregnant women specifically indicated that they believed the child in their womb to be healthier and stronger because they themselves felt heavier after using the toolkit.

> *After you spoke to me, I decided that I want my baby in my womb and myself to be very healthy and strong. I started taking the iron–folic acid pills that were bought by my husband and I am now eating three times a day even though it was difficult. I ate mangoes and pineapples for snacks. It was so difficult! I had to divide my extra meal into two halves in two sittings in order to reach the mark. [Husband] really supported me. I felt so strong afterwards and could do all the household work and had time to rest enough. After 4 days, I saw great improvements, and so I decided to try using the bowl for [daughter] after consultation with [husband]. [Daughter who is 18 months old] now eats in the bowl. Every day the quantity we give her is increasing, and she eats everything. We are very happy! We are sure that after the study, [daughter] will be eating up to the mark.* —Urban pregnant woman

Several breastfeeding women perceived that the increase in the quantity of food they ate enabled them to produce enough breastmilk for their babies. As a result, they stopped giving formula and other forms of milk, such as cow's milk, to their babies during the 14-day period.

> *Earlier I used to feel lazy. Now I don't feel like that. Everyone says the child is looking healthy and he is not crying any more and was asking why I do not give him other milk any more.* —Rural breastfeeding mother

Breastfeeding mothers also perceived their children to be more active and attributed this to having more breastmilk to feed them. Both pregnant and breastfeeding mothers believed that the involvement of their families, especially the mothers-in-law and/or husbands, during the interviews, counseling, and training sessions was useful because these household decision makers supported them in using the bowl and spoon. Indeed, family members, including mothers-in-law and fathers who were present during interviews indicated support for the toolkit and the counseling messages provided. They reported that they actively reminded the women to eat from the bowl and take their iron–folic acid. Several women, noting their own positive experiences with the toolkit, began to use it with their older children.

Use of the bowl and spoon for complementary feeding

At baseline, all 20 mothers agreed to feed their children using the bowl. The 18 mothers who had their husbands or mothers-in-law present during the counseling used the bowl and spoon as counseled. However, two rural participants were counseled in the absence of their husbands and/or mothers-in-law and only used the bowl once or twice during the first 7 days. In these cases, either their husband or their mother-in-law asked them to stop because they needed more information. During the midline visit, the mothers-in-law and/or husbands were included in counseling and their questions were addressed. Afterwards these mothers used the toolkit as instructed.

Over the 14-day testing period, all six children aged 6 to 8 months who had not initiated complementary feeding started complementary feeding. The quantity

TABLE 1. Dietary practices of pregnant and breastfeeding women in the 14-day pilot study in Samistipur District, Bihar, India

	Iron–folic acid —no. (%)		3 or 4 meals per day —no. (%)		Extra meal per day —no. (%)		Animal protein (meat or eggs)—no. (%)	
Women's status	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline
Pregnant (*n* = 20)	10 (50)	14 (70)	2 (10)	20 (100)	0 (0)	20 (100)	5 (25)	15 (75)
Breastfeeding (*n* = 20)	N/A	N/A	0 (0)	20 (100)	0 (0)	20 (100)	10 (50)	20 (100)

of food and the consumption of animal sources of food, such as eggs, meat, and fish, as well as the frequency of meals, increased in all age groups (**table 2**). The intake of vegetables and fruits also increased, based on reported estimates. The mothers reported increasing the consistency of the children's meals from more liquid to semisolid or solid. The mothers attributed the changes in these practices to the toolkit. Mothers of older children indicated that after using the toolkit, they realized that they had been underestimating the quantities their children should eat. The mothers perceived improvements in their children's weight and health and attributed these improvements to the toolkit and their new feeding practices. Some of the mothers also said that their children used to "fall ill all the time" or "they become very weak," but once they started using the toolkit their children's health improved. These perceptions motivated families to agree to continue with these new practices.

Interestingly, several mothers reported community demand for the feeding tools based on observed improvements in the participating children's health and activity, with neighbors asking to borrow the toolkits so they could also use them to measure their children's food. **Box 1** provides a representative set of quotes obtained from mothers of children 6 to 24 months of age during user testing in the home.

Focus group discussions with users after the 14-day period reiterated the tools' utility for adopting age-appropriate quantities and frequencies of food. In these discussions, participants described how the involvement of family members, especially mothers-in-law and husbands, was critical to ensure that the tools and practices would be acceptable and supported in the household. The mothers were also excited because they felt that now, when the ASHAs or AWWs were counseling, they could relate to it because they had the toolkit to help them understand and practice better once the frontline worker left the home.

> *I used to estimate the food my child would eat. I did not know the right amount to give him and ASHA also never told me the amount to feed the child. She always says I should feed my 8-month-old child two or three times a day using this measurement. She carried a bowl that she never gave to us to use and also never demonstrated in the Anganwadi center how thick the food should be. I am happy I have this bowl with the marks and spoon with holes to use… Now my child is eating at the 6- to 9-month full mark after 14 days and he is very active and healthier and does not cry like he used to.* —Rural mother of an 8-month-old child

Recommendations for tools: Design modifications and delivery platforms

Community stakeholders and participants in user testing provided extensive feedback in regard to the design of the bowl, spoon, and counseling materials and strategies for delivery of these in the communities. Overall, the overwhelming majority of the stakeholders appreciated the tools and perceived that they would be very effective in supporting appropriate dietary practices in the test communities. The idea of transitioning from the mother to the child at age-appropriate times was well received. **Box 1** presents feedback across the different categories of participants and stakeholders.

The participants overwhelmingly preferred that the bowl and spoon with the counseling cards be delivered through the Anganwadi Centers, by the ASHAs, or by project fieldworkers. These were the most frequently cited responses by the participants. The community preferred to receive the bowl and spoon for free, but if they had to be sold they should not cost more than 10 rupees because most people could not afford a higher price. They believed that if the bowl and spoon were sold it would be difficult to reach 100% coverage. The following quote highlights the nuances in the distribution and costing strategies:

> *Those who are poor will want this for free and those who have money will say that they will buy it. Even the poor, those who want it, can buy it for less than 5 rupees. If you want everyone to use it then distributing it for free will be most beneficial. If you want then you can give it to the Anganwadi, children come there too. They know about all the places and can give it to the mothers. ASHAs too can distribute because they come to the houses but it will be best if you come and distribute and counsel like you did to us because ASHAs will not have time to come and do it. They come to the houses once a year or not at all and when they come they are in a hurry to leave.* —Rural mother of a 9-month-old child

Finally, the participants in user testing noted that inclusion of other family members in the counseling, especially mothers-in-law and husbands, was critical.

TABLE 2. Dietary practices of children 6 to 24 months of age in the 14-day pilot study in Samastipur District, Bihar, India

Age group	Initiated complementary feeding—no. (%)		Consuming recommended number of meals per day—no. (%)		Average amount consumed per meal—g		Consuming animal protein (meat or eggs)—no. (%)	
	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline
6–8 mo (n = 6)	0 (0)	6 (100)	0 (0)	6 (100)	0	96	0 (0)	6 (100)
9–11 mo (n = 6)	6 (100)	6 (100)	0 (0)	6 (100)	69	143	0 (0)	6 (100)
12–24 mo (n = 8)	8 (100)	8 (100)	0 (0)	8 (100)	111	181	8 (100)	8 (100)

They felt that their families had great understanding and their questions were answered during the counseling so they were more accepting and they also observed the benefits of the bowl and spoon. The mothers claimed that when they forgot to use the bowl, their husbands or mothers-in-law served as reminders. One pregnant woman said:

> *My husband and my mother-in-law are very supportive in the usage of the bowl and spoon. Sometimes when I forget, they ask me and then I remember to go and take my iron–folic acid and use the bowl and spoon to eat.*

BOX 1. Feedback on user testing of the bowl, spoon, and counseling materials to guide complementary feeding among families with children 6 to 24 months of age

Even though he is 8 months, I [had] not started feeding him food. Now after you counseled, he eats roti mixed with sugar and milk. He now plays a lot. He is very active and only cries when he is hungry. He eats 3/4 of the 6- to 9-month mark per meal and I feed him three times a day and two times snacks per day. I give him pomegranate juice and sometimes apple juice. —Urban mother

Now my child has started complementary feeding and so he is very active and the crying has reduced. He plays a lot and eats a lot. When he is tired he sleeps. I believe it is because he is eating the right amount of food because of the mark on the bowl. Also, he eats semisolid and thick food because of the spoon. I see he has also become heavy and stronger. —Rural mother of a 7-month-old child

[Name of child] does not allow anyone to feed her. She likes to feed herself and she eats 3/4 of the 12- to 24-month mark three times a day and likes eating mango too. She has become very active and healthy and she likes eating meat a lot. I mash it and give to her. My sister-in-law's son has also started using the bowl. —Rural mother of a 13-month-old child

[Name of child] looks healthier, heavy, and stronger after I started giving him food up to the 9- to 12-month mark and checking the thickness with the spoon. The spoon is too big and sharp so I feed him with my hand. I even now mash fish or egg or meat and add it to dal-rice with cauliflower and patel. ……I also feed him three times a day the same amount and give him snacks like mango juice and apple juice and milk and biscuits. My sister-in-law also now takes the bowl and spoon to feed the child who is 12 months because she said she has seen that my child is growing very well. —Rural auntie of a 10-month-old child

We do not use plastic to eat because it is difficult to clean and can bring about hygiene problems. We measure the food in it and put it in a steel plate for [name] to eat. The marks on the bowl and holes in the spoon are very helpful. If it is put on steel everyone will use it and we will be giving our children the right amount and thickness of food. —Rural auntie of a 9-month old child

Relatives living in the same homes with some of the participants who had children between 6 and 24 months of age also reported using the bowl and spoon to feed their children, since they believed this improved the health of the children. A mother of an 8-month-old in the urban site said:

> *I now feed my child three times a day and my husband and mother-in-law support me. When I am away, my mother-in-law feeds the child with the bowl and spoon and my husband serves as our reminder.*

Recommendations and design improvements

With regard to the design of the bowl and spoon, many felt that the spoon was too "sharp" and big and might not enter a child's mouth. They strongly preferred that the bowl and spoon be made of steel, as plastic was not perceived to be locally acceptable to use for eating. They cited hygiene concerns with the plastic bowl and spoon. They also indicated that steel bowls and spoons are traditionally used to make sounds as a feeding strategy to help maintain children's attention during feeding.

Discussion

Our findings suggest that an innovative feeding toolkit consisting of a marked bowl, slotted spoon, and an accompanying pictorial counseling card is highly acceptable and can be used by families in the home to improve dietary practices of women during pregnancy and the postpartum period and the quantity and quality of feeding of their young children. This toolkit focuses on giving cues to a broad range of factors that affect dietary practices, including meal frequency, consistency, and quality (the latter through the counseling card). The marks on the bowl proved useful for both pregnant and breastfeeding women to cue extra food consumption and for mothers with young children to cue appropriate meal frequency and volume. The slotted spoon proved useful for determining the consistency of porridge, and the mothers indicated that they adjusted the food to a better thickness as a result of testing with the spoon (i.e., if the porridge passed through the slots). The illustrated counseling cards, in addition to cueing diet diversity, also proved to be very useful teaching tools for participating families. They were able to use them to teach other family members who might not have been present at a counseling session, clarify information in the event of confusion or disagreement, and share the information with neighbors.

In the study context, the mothers insisted that the involvement of family members, especially mothers-in-laws and husbands, during nutrition education and counseling influenced uptake of the tools and counseling recommendations. Even though frontline workers were believed to have some influence on the nutrition of mothers and children, the mother-in-law was perceived to have greater influence. This is consistent with a recent review by Aubel [14], which found that, across multiple contexts, elderly women in the family (grandmothers and mothers-in-law) are the primary influencers and decision makers for dietary practices and nutrition of pregnant and lactating women and infants. Aubel [14] concluded that appropriately engaging grandmothers in maternal and child nutrition programs may substantially improve their effectiveness. A formative study conducted in Senegal also showed the need for future maternal and child health programs in different cultural contexts to involve grandmothers, as they have the ability to learn, integrate new information into their practices, and positively influence the practices of women of reproductive age [15]. Engagement of fathers in nutrition programs similarly may increase their effectiveness in some contexts. In a study in Vietnam, the practice of involving the fathers during breastfeeding promotion caused a change in the men's knowledge and beliefs and an improvement in their roles in supporting breastfeeding [16].

Although the formative results are promising, there are limitations to the present work. The intensive counseling from trained research assistants does not provide a realistic view of counseling practices as they would occur in a programmatic, real-world setting. The families received intensive counseling together with the bowl, spoon, and counseling card, and therefore we are unable to distinguish which interventions (counseling, counseling card, or bowl and spoon) were the primary drivers of behavior change. Further testing requires adequate control populations. Finally, our study did not quantify nutrient intakes; rather, the changes in dietary practices and intakes described here are largely qualitative.

In conclusion, this formative research has illustrated the potential of a single, easy-to-use toolkit as an acceptable intervention to increase dietary intakes of women during pregnancy and lactation and of children during the period of complementary feeding, which may in turn improve the nutritional status of both mothers and children. Further research that is adequately powered and includes a control group could help to determine the efficacy of the bowl and spoon to improve intakes beyond enhanced counseling alone. Cost-effectiveness research may also help justify the provision of the bowl and spoon in addition to counseling. When designing the tools and the study, future studies should consider the recommendations made by the community, namely, the use of steel bowls and the recommended operational platforms for delivery.

Authors' contributions

Amy Webb Girard conceptualized the feeding toolkit. Jonathan Colton, Wendy Blount, and Sarah Melgen developed the prototypes of the bowl and spoon. Deborah Kortso Collison, Nidal Kram, Sarah Melgen, Priya Kekre, Pankaj Verma, and Amy Webb Girard developed the field testing protocol. Deborah Kortso Collison led the data collection and analysis and wrote the first draft of the manuscript. All authors critically reviewed the draft and provided substantial input.

Acknowledgments

The team gratefully acknowledges financial support from a Bill & Melinda Gates Foundation, Grand Challenges Explorations Award and logistic and financial support from the Integrated Family Health Initiative, CARE India.

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Gardening practices in a rural village in South Africa 10 years after completion of a home garden project

Tisungeni Zimpita, Chara Biggs, and Mieke Faber

Abstract

Background. *Few studies have documented whether the behavior changes produced by home garden projects have been maintained after completion of the projects.*

Objective. *To determine the benefits and challenges affecting production and consumption of β-carotene–rich vegetables and fruits in a rural South African village 10 years after completion of a home garden project.*

Methods. *This cross-sectional survey assessed gardening practices and household consumption of β-carotene–rich vegetables and fruits using a questionnaire (*n *= 186). Benefits and challenges affecting production and consumption of β-carotene–rich vegetables and fruits were assessed through focus group discussions.*

Results. *Thirty-nine percent of the households currently planted β-carotene–rich vegetables and fruits. Major challenges included lack of fencing, animals eating crops, and lack or shortage of water. Planting materials for β-carotene–rich vegetables were sourced from the community nursery, while papaya was grown from its own seed. Shops were the most likely alternative sources of β-carotene–rich vegetables. The frequency of consumption of orange-fleshed sweet potato, butternut, spinach, and papaya when in season differed significantly, with households planting β-carotene–rich vegetables and fruits having more frequent consumption than households not planting these vegetables and fruits. Households planting β-carotene–rich vegetables and fruits were perceived as "well-to-do" and "healthy" households and as "givers."*

Conclusions. *This study showed that 10 years after the endline evaluation of a home garden project, approximately one-third of the households in the village planted β-carotene–rich vegetables and fruits, which is very similar to the proportion at project completion and a postintervention study that was done 6 years later, despite various challenges, indicating that the practice of planting these vegetables and fruits was continued over the years.*

Key words: Home gardening, postintervention, South Africa, vitamin A

Introduction

Food-based interventions aimed at reducing micronutrient malnutrition through increased production and consumption of micronutrient-rich foods include a variety of long-term strategies, such as home gardens, small-scale commercial farming, and small-livestock production; nutrition education, social marketing, and communication; and optimal food preparation methods that ensure retention of micronutrients [1–3]. Successful food-based interventions usually incorporate a mixture of activities, such as home gardening, nutrition education, and food processing and preservation. Food-based interventions generally empower households to take an active role in improving the quality of their diets, are culturally acceptable and thus have the potential to be incorporated into routine household activities, result in increased dietary intakes of multiple nutrients, and have the potential for income generation, as well as strengthening community development and empowerment of women [1, 4, 5].

A systematic review of the effects of household food production strategies on health and nutrition outcomes showed that most nutrition-sensitive agricultural studies, including home gardens (with or without animal production strategies), were associated with increased dietary diversity, increased consumption of β-carotene–rich vegetables and fruits, increased intake of other vegetables and fruits, and increased intake of legumes [6].

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With the exception of the Helen Keller International homestead food production program [7], few projects have documented whether the changed behavior has been maintained after completion of the project [8, 9], and it has been argued that activities of community-based interventions have a tendency to be discontinued upon project completion, even though sustainability strategies were put in place [10, 11]. According to Sarriot et al. [12], maintenance of behavior is affected by three factors: project design and implementation, organizational setting, and community environment. Postevaluations of food-based interventions are usually limited and do not measure confounding factors and exit strategies that have an impact on maintenance of behaviors [1, 13]. Repeated postevaluation is thus crucial in documenting the challenges and sustained benefits of food-based interventions [9].

The Ndunakazi home-gardening project, which had the aim of promoting the production and consumption of β-carotene–rich vegetables and fruits to reduce vitamin A deficiency in a South African rural village, showed favorable effects on dietary vitamin A intake and serum retinol concentrations in children [14, 15]. In the Ndunakazi project, gardening activities were integrated with an existing community-based growth-monitoring project, which served as an entry point for nutrition education and training in gardening activities. The project targeted all mothers or caregivers who brought their children under 5 years of age for monthly growth-monitoring. During the growth-monitoring sessions, planting and consumption of β-carotene–rich vegetables (including β-carotene–rich orange-fleshed sweet potato) and fruits were promoted; this was done through training in demonstration gardens, nutrition education focusing on vitamin A and health, and preparation of β-carotene–rich vegetables. A postevaluation study done approximately 6 years after project completion suggested that the improved vitamin A nutritional knowledge, gardening activities, and improved nutritional behavior were being maintained after the withdrawal of the research organization [16]. At the end of the project, in November 2000, and during the postevaluation study done in March to May 2007, it was estimated that 33% to 40% of the households planted β-carotene–rich vegetables and fruits [15, 16]. The aim of this study was to assess whether improved nutrition behaviors still existed in the population 10 years after project completion, and to determine the benefits and challenges affecting sustained production and consumption of β-carotene–rich vegetables and fruits.

Methods

Research design

The study purposively sampled all households residing between two demarcated points in a rural mountainous village of low socioeconomic status located approximately 60 km northwest of the coastal city of Durban in KwaZulu-Natal Province, South Africa. Of the 196 households visited, 186 were assessed. The study was done in October and November 2010 and consisted of two phases. The first phase used a quantitative cross-sectional approach to assess gardening practices and consumption of β-carotene–rich vegetables and fruits. The second phase used a qualitative descriptive approach, using focus group discussions to assess benefits and challenges affecting production and consumption of β-carotene–rich vegetables and fruits.

Phase 1: Quantitative questionnaire data

An interviewer-administered structured questionnaire was completed for one female household member responsible for food preparation per household. The questionnaire was developed to collect information on sociodemographics, including age and marital status of the respondent, main source of income of the household, household composition, source of drinking water, and source of cooking energy. Information on knowledge of vitamin A, home-gardening practices of growing β-carotene–rich vegetables and fruits, and dietary practices was also collected. The usual frequency of consumption of β-carotene–rich vegetables and fruits, when in season, during the previous 12 months was recorded as at least 3 days per week, 1 or 2 days per week, seldom, or never. The questionnaire was pretested in 10 conveniently selected women in a nearby village and was revised where needed. Four nutrition monitors, who were also involved in the previous evaluations in the area [14–16], were trained during a 3-day workshop. The questionnaire was translated into the local vernacular (isiZulu) and administered to the respondents by the nutrition monitors during household visits.

Phase 2: Qualitative focus group discussions

The list of respondents who participated in phase 1 of the study was used to randomly select 20 respondents who planted β-carotene–rich vegetables and fruits and 20 respondents who did not have home gardens. Four focus group discussions were conducted, each including 10 participants. The focus group discussions were conducted in the local vernacular by a professional facilitator who explained the purpose of the meeting to the respondents. The discussions were recorded with a digital recorder, and notes of the discussions were taken. During the focus group discussions, flip charts were used and a participatory approach was encouraged. The two focus group discussions with participants who planted β-carotene–rich vegetables and fruits started with the participants drawing their home gardens and the vegetables and fruits grown. The two focus group discussions with participants who did not have home gardens started with the participants drawing a typical household in the village, indicating the various vegetables and fruits that were planted. This was done in groups of four or five respondents. The facilitator used these drawings to initiate a discussion of which vegetables and fruits were commonly grown in the village and the reasons for growing or not growing them. Questions in the focus group discussion guide for participants who planted β-carotene–rich vegetables and fruits related to the use of these vegetables and fruits, as well as the benefits and challenges experienced in their production and consumption. Questions for participants without home gardens related to why they did not have vegetable gardens and what benefits and challenges they envisaged in having a vegetable garden.

The recordings and notes were analyzed by sorting the information into each question category. Themes and categories were identified and assigned by looking for patterns and contrasts from the discussion that related to the topic of interest. The results related to production and consumption (actual and envisaged) of β-carotene–rich vegetables and fruits were interpreted within the context of strengths, weaknesses, opportunities, and threats.

Ethical considerations

Ethical clearance was obtained from the Social Science and Humanities Ethics Committee of the University of KwaZulu-Natal (HSS/0811/2010). Permission to carry out the study in the village was obtained from the community leader. Written informed consent was obtained from each study participant after the nature and purpose of the study had been explained to them in the local language vernacular (isiZulu).

Data management and analysis

Data from the household questionnaire were analyzed with SPSS, version 18.0. The households were grouped according to whether they planted β-carotene–rich vegetables and fruits or not. Households that planted at least two different types of β-carotene–rich vegetables and fruits were classified as households planting β-carotene–rich vegetables and fruits, regardless of plot size. The continuous variables age and number of household members were tested for normality by the Shapiro–Wilk test. These data were not normally distributed and are presented as medians and interquartile ranges (IQRs). Households planting or not planting β-carotene–rich vegetables and fruits were compared with Pearson's chi-square and Mann–Whitney U tests, and a two-sided p value < .05 was considered to indicate statistical significance.

Results

Phase 1: Quantitative questionnaire data

Household characteristics

Of the 196 households visited, 186 (95%) participated in the study. Nonparticipation was mainly because the caregivers of the households were not available during the initial visit or on a revisit. A summary of household characteristics is given in **table 1**. The median number of people per household was seven (IQR, five to nine), with no difference between those planting β-carotene–rich vegetables and fruits and those not planting these vegetables and fruits. The majority of the households had access to tap water (93%, 173/186), either through their own tap, their neighbor's tap, or a communal tap. More households who planted β-carotene–rich vegetables and fruits had their own tap than those not planting these vegetables and fruits (97.3%, 71/73, versus 67.3%, 76/113; p = .001). The majority of households used electricity as the main source of energy for cooking (62.9%, 117/186). Fifty-five per cent (103/186) of the households relied on social grants as their main source of income. There was a trend (p = .050) for households planting β-carotene–rich vegetables and fruits to rely more on social grants and self-employment as sources of income in comparison with those not planting these vegetables and fruits, who relied more on formal employment as the main source of income.

Compared with respondents from households who did not plant β-carotene–rich vegetables and fruits, respondents from households who planted these vegetables and fruits were older (median, 47 years [IQR, 31 to 61] versus 36 years [IQR, 25 to 52]; p = .009), and a smaller proportion were single (38%, 28/73, versus 53%, 60/113; p = .036). The level of formal school education differed between the two groups (p =.039), with those not planting β-carotene–rich vegetables and fruits being more educated and more likely to have at least a high school education.

Only 19.9% of the respondents knew that vitamin A is a nutrient in food. Respondents planting β-carotene–rich vegetables and fruits seemed to have a better knowledge of vitamin A, with 65.8% (48/73) correctly naming at least one symptom related to vitamin A deficiency, versus 44.2% (50/113) of those not planting these vegetables and fruits, and 58.9% (43/73) correctly naming at least three vitamin A–rich vegetables or fruits, versus 35.4% (40/113) of those not planting these vegetables and fruits.

Households planting β-carotene–rich vegetables and fruits

Thirty-nine per cent (73/186) of the households planted at least two β-carotene–rich vegetables and fruits. Ninety-nine per cent (72/73) of these households used the β-carotene–rich vegetables or fruits for home consumption, 13.7% (10/73) exchanged some for other foods, and 5.5% (4/73) sold some. Most believed that home gardens supplied food (82.2%, 60/73) and saved money (67.1%, 49/73). The β-carotene–rich vegetables and fruits normally planted included spinach (95.9%, 70/73), carrots (79.4%, 58/73), butternut (49.3%, 36/73), orange-fleshed sweet potato (30.1%, 22/73), and papaya (32.9%, 24/73). Challenges faced by households planting β-carotene–rich vegetables and fruits were mostly animals eating crops (46.6%, 34/73), lack of fencing (32.8%, 24/73), and shortage of water (17.8%, 13/73). Sixty-eight percent (50/73) of these households had problems with pests and plant diseases in their gardens. Of these, 56% (28/50) used chemical methods to control the infestations. Seventy-seven per cent (56/73) of the households planting β-carotene–rich vegetables and fruits weeded their gardens as soon as the weeds appeared, 93.1% (68/73) practiced crop rotation, 32.8% (24/73) practiced mulching, and 32.9% (24/73) practiced intercropping. The sources of planting material are shown in **table 2**. The community-based nursery was the main source of planting material for

TABLE 1. Summary of characteristics of the participants

Characteristic	All (*n* = 186)		Planting β-carotene–rich VF (*n* = 73)		Not planting β-carotene–rich VF (*n* = 113)		*p*[a]
	Median	IQR	Median	IQR	Median	IQR	
Age (yr)	41	26–57.5	47	31–61	36	25–52	.009
No. of people per household	7	5–9	7	5–11	7	4–9	.417
	Freq.	%	Freq.	%	Freq.	%	
Marital status							.036
Single	88	47.3	28	38.4	60	53.1	
Married	69	37.1	28	38.4	41	36.3	
Widowed	29	15.6	17	23.3	12	10.6	
Educational level							.039
No schooling	56	30.1	28	38.4	28	24.8	
Primary school	49	26.3	19	26.0	30	26.5	
High school	64	34.4	17	23.3	47	41.6	
Passed grade 12	17	9.1	9	12.3	8	7.1	
Main source of household income							.050
Social grant	103	55.4	45	61.6	58	51.3	
Employment	62	33.3	17	23.3	45	39.8	
Self-employed	21	11.3	11	15.1	10	8.8	
Main source of drinking water							.001
Own tap	147	79.0	71	97.3	76	67.3	
Neighbor's or communal tap	26	14.0	2	2.7	24	21.2	
Water tanker or river	13	7.0	0	0	13	11.5	
Main source of energy for cooking							.263
Electricity	117	62.9	51	69.9	66	58.4	
Gas or paraffin	8	4.3	2	2.7	6	5.3	
Wood or charcoal	61	32.8	20	27.4	41	36.3	
Vitamin A knowledge							
Knew vitamin A is a nutrient in food	37	19.9	17	23.3	20	17.7	.036
Correctly named at least 1 symptom of vitamin A deficiency	98	52.7	48	65.8	50	44.2	.004
Correctly named 3 vitamin A–rich VF	83	44.6	43	58.9	40	35.4	.002

IQR, interquartile range (25th–75th percentiles); VF, vegetables and fruits
a. Mann-Whitney U test (continuous data); chi-square test (categorical data).

β-carotene–rich vegetables, while papaya was mainly grown from its own seed.

Consumption of β-carotene–rich vegetables and fruits

The frequency of household consumption of the specific β-carotene–rich vegetables and fruits, when in season, is given in **table 3**. The frequency of consumption differed significantly between those households who planted β-carotene–rich vegetables and fruits and those who did not for orange-fleshed sweet potato, butternut, spinach, and papaya, with a more frequent consumption in households planting β-carotene–rich

TABLE 2. Sources of planting materials for β-carotene–rich vegetables and fruits, expressed as a percentage of those who planted the specific vegetable or fruit

	Spinach (*n* = 70)		Carrots (*n* = 58)		Butternut (*n* = 36)		Orange-fleshed sweet potato (*n* = 22)		Papaya (*n* = 24)	
Source	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Community-based nursery	52	74	45	78	31	86	20	91	0	0
Shop and/or market[a]	10	15	7	12	2	5	0	0	1	4
Agricultural extension officer	7	10	4	7	2	5	0	0	1	4
Neighbor	1	1	2	3	0	0	0	0	1	4
Own seed or cutting	0	0	0	0	1	3	2	9	21	88

a. markets include both formal and informal markets; informal markets refer to selling goods nest to the road, at taxi ranks, etc.

TABLE 3. Frequency of consumption of β-carotene–rich vegetables and fruits (VF) when in season

		Households planting β-carotene–rich VF (*n* = 72)		Households not planting β-carotene–rich VF (*n* = 113)		
Vegetable or fruit	Frequency of consumption	Freq.	%	Freq.	%	*p**
Orange-fleshed sweet potato	Never	22	30.6[a]	58	51.3[b]	.001
	Seldom	18	25.0[a]	34	30.1[a]	
	1–2 days / week	26	36.1[a]	19	16.8[b]	
	≥ 3 days / week	6	8.3[a]	2	1.8[b]	
Butternut	Never	2	2.8[a]	5	4.4[a]	.003
	Seldom	2	2.8[a]	25	22.1[b]	
	1–2 days / week	45	62.5[a]	56	49.6[a]	
	≥ 3 days / week	23	31.9[a]	27	23.9[a]	
Pumpkin	Never	16	22.5	31	27.4	.089
	Seldom	15	21.1	39	34.5	
	1–2 days / week	31	43.7	35	31.0	
	≥ 3 days / week	9	12.7	8	7.1	
Carrots	Never	6	8.5	14	12.8	.061
	Seldom	0	0.0	8	7.3	
	1–2 days / week	24	33.8	38	34.9	
	≥ 3 days / week	41	57.7	49	45.0	
Spinach	Never	0	0.0[a]	3	2.7[a]	.009
	Seldom	3	4.2[a]	20	17.9[b]	
	1–2 days / week	57	79.2[a]	66	58.9[b]	
	≥ 3 days / week	12	16.7[a]	23	20.5[a]	
Papaya	Never	15	20.8[a]	36	32.1[a]	.020
	Seldom	8	11.1[a]	25	22.3[a]	
	1–2 days / week	28	38.9[a]	25	22.3[b]	
	≥ 3 days / week	21	29.2[a]	26	23.2[a]	

Each subscript letter denotes a subset of categories that do not differ significantly from each other at the .05 level (Bonferroni multiple comparison test).
*Chi-square test.

TABLE 4. Alternative sources of β-carotene–rich vegetables and fruits (VF) when they are not grown or when stores are depleted

Source	Orange-fleshed sweet potato				Butternut				Carrot				Spinach				Papaya			
	Planting β-carotene–rich VF (n = 73)		Not planting β-carotene–rich VF (n = 113)		Planting β-carotene–rich VF (n = 73)		Not planting β-carotene–rich VF (n = 113)		Planting β-carotene–rich VF (n = 73)		Not planting β-carotene–rich VF (n = 113)		Planting β-carotene–rich VF (n = 73)		Not planting β-carotene–rich VF (n = 113)		Planting β-carotene–rich VF (n = 73)		Not planting β-carotene–rich VF (n = 113)	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Did not get VF from anywhere	30	41	35	31	1	1	5	4	1	1	4	4	8	11	4	4	18	25	23	20
Bought from shops or market	28	38	52	46	68	94	106	94	69	95	105	93	44	61	78	69	9	12	4	3
Asked from friends or neighbors	13	18	26	23	2	3	1	1	2	3	3	2	20	27	31	27	39	54	83	74
Used alternative VF	1	2	0	0	1	1	0	0	1	1	1	1	0	0	0	0	2	2	0	0
Started using stored VF	1	1	0	0	1	1	1	1	0	0	0	0	1	1	0	0	5	7	3	3

vegetables and fruits. There was no significant difference between the two groups in frequency of consumption of pumpkin and carrots.

Table 4 indicates the alternative sources of β-carotene–rich vegetables and fruits when they were not grown or when stored ones were depleted. When these vegetables and fruits were not obtained from their own gardens, the majority of households in both groups bought butternut, carrots, and spinach from shops and markets. The orange-fleshed sweet potato was either not obtained from anywhere or bought from informal markets. Papaya was mostly obtained from neighbors and friends.

Phase 2: Qualitative focus group discussions

Respondent's perceptions of β-carotene–rich vegetable home gardens and β-carotene–rich vegetables normally eaten

Participants from the focus group discussions who were growing β-carotene–rich vegetables and fruits viewed owning a home garden more of an obligation than an option to produce food for home consumption; they felt that "as women and as mothers, we need to cook and see that there is food for all" and "a vegetable home garden is an extension of the kitchen that ensures food on the table."

Both groups considered households growing β-carotene–rich vegetables and fruits as"well-to-do households" because they were able to reduce household expenditure, as well as "healthy households" because they ate "fresh" β-carotene–rich vegetables and "nutritious foods" that helped them fight disease. Households growing β-carotene–rich vegetables and fruits were also considered as "givers" by participants without home gardens because they shared their surplus with their neighbors, although they did not like accepting vegetables because they felt it jeopardized their dignity and respect. Respondents from households growing β-carotene–rich vegetables and fruits said "people who are lazy come to us to ask for vegetables."

When asked how often specific β-carotene–rich vegetables and fruits were eaten and why, respondents said that spinach was eaten most often because it was available throughout the year either in shops or in gardens, and it was easy to prepare and healthy. Carrots were eaten often because they could also be eaten raw. Butternut was eaten often because it could be eaten as a snack, it was easy to prepare, and children preferred it to other vegetables. Even though both groups indicated that orange-fleshed sweet potato cooked faster and could be eaten as a snack, it was only available for a short period in the year and therefore was the least-eaten vegetable.

Both groups reported a shortage of water for irrigation, lack of fencing, and limited agricultural extension services as weaknesses. Respondents who did not have home gardens felt that they lacked knowledge about how to start up a home garden because of the limited agricultural services in the area. Respondents who planted β-carotene–rich vegetables and fruits said that roaming animals destroyed the plants because of the lack of fencing. According to respondents without home gardens, lack of time for maintaining the fence was a challenge. Limited availability and the cost of seeds were seen as a challenge by respondents planting β-carotene–rich vegetables and fruits, while lack of money to buy seeds was seen as a challenge by those without home gardens. According to respondents who planted β-carotene–rich vegetables and fruits, they lacked knowledge of new agricultural practices and on storage and preservation of vegetables.

Both groups viewed the availability of land for increased production and the desire to be labeled as healthy or well-off as opportunities for the start-up and maintenance of home gardens. In addition, respondents who planted β-carotene–rich vegetables and fruits viewed the existence of the community-based nursery, people's enthusiasm about planting these vegetables and fruits, the availability of new agricultural technologies, and the prospect of selling surplus vegetables and fruits as opportunities for maintenance of home gardens.

Both groups highlighted unpredictable weather as the main threat to planting a home garden. Other threats to participants who planted β-carotene–rich vegetables and fruits were the repossession of land by the chiefs when a home garden was not taken care of by its owner, and male household members taking over the home garden production once there was sufficient surplus to be sold.

Discussion

Approximately one-third (39%) of the households grew their own β-carotene–rich vegetables and fruits, a proportion very similar to that at the end of the project in November 2000 [15] and the postintervention evaluation study that was done in 2007 [16]. This finding suggests that postproject garden activities were still ongoing in the village. In the late 1990s, before the onset of the gardening project, households in the village planted pumpkin and, to a lesser extent carrots, although these vegetables were not frequently consumed [17]. The project introduced a variety of β-carotene–rich vegetables and fruits, such as butternut, orange-fleshed sweet potato, spinach, and papaya, all of which were still grown and consumed 10 years after completion of the project. Of those households planting β-carotene–rich vegetables and fruits, most applied good gardening practices, such as weeding and crop rotation, which were promoted during the original project. Focus group discussion data showed that households were motivated to plant β-carotene–rich vegetables and fruits because they provided food for household consumption, resulted in a reduction in household expenditure, and were perceived to have positive socioeconomic implications, such as the household's being labeled as a "giver" or "well-to-do." This is very similar to the results of the end evaluation in November 2000 [15], which showed that planting β-carotene–rich vegetables and fruits was related to not having to buy vegetables and poverty alleviation.

Challenges experienced by households planting β-carotene–rich vegetables and fruits (lack of water and fences, crops being destroyed by animals, and plant pests and diseases) were similar to those reported in the endline and postintervention evaluation studies [15, 16]. Fencing is an expensive item for poor households, and lack of fencing will probably remain a challenge as long as poverty prevails in the area.

The community-based nursery that was established to improve access to orange-fleshed sweet potato planting material and high-quality seeds at an affordable price as part of the exit strategy after the endline evaluation [16] was the main source of β-carotene–rich vegetable planting material. Community-based nurseries are also part of the successful Helen Keller International projects in Cambodia and Bangladesh [18, 19]. Community-based nurseries do not, however, guarantee household access to planting material, as was shown in a project in South Africa where the community had access to a continuous supply of orange-fleshed sweet potato planting material through a field nursery, yet a lack of cuttings was reported as a challenge in the project [20]. Lack of planting material for orange-fleshed sweet potato [21, 22] and inadequate supply of quality seeds [5] have been reported as barriers in home garden projects. At the time of the study, the community-based nursery was managed by a community member employed by the research organization. However, the employment of this community member was recently terminated because of restructuring within the organization. Sustainable community access to planting materials may therefore become challenging. An evaluation within the next few years is needed to ascertain whether the community would be able to sustain the nursery without external support.

Spinach was the most commonly grown and regularly eaten β-carotene–rich vegetable, probably because the community had access to wild-growing dark-green leafy vegetables before implementation of the garden project [17]. Orange-fleshed sweet potato, which is available to a limited extent for a short period of time in season, was the least commonly grown and consumed β-carotene–rich vegetable. A survey in 2003 in the area also showed low consumption of orange-fleshed sweet potato, and it was argued that orange-fleshed sweet potato does not easily blend into the traditional way of eating [23]. Sweet potato is not a common staple food in South Africa, as is the case in other parts of Africa [21, 24, 25], and the orange variety is unfamiliar to the average South African. It can be argued that a more intensive long-term promotion campaign encouraging local production is needed. The inclusion of a market development strategy could also lead to an increase in the production of orange-fleshed sweet potato, as was shown in Mozambique [25, 26] and Uganda [24].

Households planting β-carotene–rich vegetables and fruits ate these vegetables more frequently when in season than households not planting these vegetables and fruits, a finding similar to that reported in other studies [7, 14, 18-21, 24–29]. Direct comparisons with other surveys reporting dietary intake in the village and surrounding areas are challenging because of seasonal variability in the availability and consumption of these vegetables and fruits [23]. The more frequent consumption of β-carotene–rich vegetables and fruits by households planting these vegetables and fruits is, however, seen as an important benefit of home production, as β-carotene–rich vegetables and fruits are not freely available in the local shops in the village [23].

Ideally, home gardens should provide a continuous year-round supply of β-carotene–rich vegetables and fruits. The seasonal variation in the availability of these vegetables and fruits is therefore a challenge in food-based interventions aimed at addressing vitamin A deficiency [23, 27]. Crop rotation that incorporates cool- and warm-weather vegetables can assist in overcoming seasonality in Africa [30, 31]. In Asia, "improved" home gardens that produce vegetables and fruits all year round were promoted in the Helen Keller International projects, in essence improving both availability and diversification [18].

Most households did not store their β-carotene–rich vegetables and fruits to overcome seasonal shortages. Lack of knowledge of storage and preservation methods was highlighted in the focus group discussions. In a study in Tanzania, solar drying was introduced to prolong the shelf life and thus the availability and possibly the consumption of β-carotene–rich vegetables and fruits during the off-season [27]. When storage and drying techniques are introduced to prolong the availability of β-carotene–rich vegetables and fruits, cost and nutrient retention should be taken into account, as high temperatures, exposure to light during processing, and prolonged storage degrade the β-carotene content in vegetables and fruits [32].

Only 5.5% of the households sold their surplus of β-carotene–rich vegetables and fruits, which was expected as the previous project focused on household food consumption, rather than on income generation. During the endline evaluation in 2000, only 8% of households sold some of the produce [15]. According to the model of sustainability described by Shediac-Rizkallah and Bone [33], continued benefits for individuals after project completion affect the maintenance of behaviors and sustainability. Bushamuka et al. [7] reported that home gardens strengthen the ability of households to access food and have a role in increasing household income. In Cambodia, households with home gardens had a significant improvement in household income derived from the sale of home garden produce, and income from home gardens was mostly used to purchase additional food for the household [19]. In the Mozambique project, an increase in participation and household income was observed when a market development component was added [26]. For long-term sustainability of food-based interventions, local shop owners should be included in vitamin A promotion campaigns. For example, in the large-scale studies done in Mozambique [25] and Uganda [24], local orange-fleshed sweet potato traders were included in the orange-fleshed sweet potato campaigns. During the original project, the local shop owner in the village did see the opportunity and introduced butternut into the local shops [14]. This was, however, not maintained, as a survey in 2004 showed that butternut was not available in any of the local shops [23].

It can be assumed that gardening activities are dynamic over time, with some households discontinuing and others starting to plant. Twenty-three percent of the respondents were 25 years of age or younger, and it would not have made sense to have them answer questions about what happened 10 years ago during the original project. Respondents who did not plant β-carotene–rich vegetables and fruits were younger and less knowledgeable about vitamin A. The proportion of respondents who could correctly name three β-carotene–rich vegetables or fruits and/or at least one symptom related to vitamin A deficiency was lower than it was at the end of the project in 2000 [15]. This, together with the limited agricultural extension services in the area, may lead to a decline in the planting of β-carotene–rich vegetables and fruits in the village within the next few years.

In summary, this study showed that 10 years after completion of a home garden project, approximately one-third of the households in the village planted β-carotene–rich vegetables and fruits, a very similar proportion to that at project completion in November 2000 [15], a result suggesting that postproject garden activities were still ongoing in the village. Households planting β-carotene–rich vegetables and fruits had a more frequent consumption of some of the β-carotene–rich vegetables and papaya. Perceived benefits of planting β-carotene–rich vegetables and fruits included food supply, reduction in household expenditure, and the perception of being labeled as "givers," "well-to-do," and "healthy households." Challenges to maintaining gardens were lack of water and fences, destruction of crops by animals, and plant pests and diseases.

Authors' contributions

Tisungeni Zimpita designed the study, collected and analyzed the data, and wrote the first draft of the paper. Chara Biggs supervised the design of the study; data collection, analysis and interpretation; and gave academic input; Mieke Faber was involved in the design of the study, gave academic input, and finalized the paper. All authors read and approved the final version of the paper.

Acknowledgments

The authors thank the respondents who participated in the study; the nutrition monitors, who assisted with data collection; Dr. Unathi Kolanisi, who facilitated the focus group discussions; and Oliver Bodhlyera, who assisted with the statistical analysis. Funding for the study was obtained from the Forum for Agricultural Research for Africa.

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Micronutrient program costs: Sources of variations and noncomparabilities

John L. Fiedler and Chloe Puett

Abstract

Background. *Micronutrient interventions are contributing to substantial reductions in global morbidity and mortality. As the diversity and coverage of these interventions expand, it is increasingly important to understand their distinct roles and contributions, and the resources they require. To date, comparing program resource use has been hampered by several noncomparabilities in cost studies relating to diverse intervention activities and service delivery pathways, along with differences in methodological approaches.*

Objective. *To promote better understanding of the variations and noncomparabilities in costs and cost structures of micronutrient interventions.*

Methods. *Cost studies on supplementation, fortification and biofortification programs from the published and gray literature were reviewed (n = 130).*

Results. *Specific areas of noncomparability identified include intervention characteristics and country context, as well as differences in methodological considerations, including data sources and definition of cost centers. Moreover, analyses vary significantly in terms of types of costs included. Implications and practical recommendations for standardizing future costing studies are provided.*

Conclusions. *Methodological variations and noncomparabilities do much more than limit the ability to make direct comparisons of costing studies; they carry important implications for the adoption, design, and implementation of interventions in countries suffering from micronutrient deficiencies. This study synthesizes evidence on the level of support required (both financial and otherwise) for programs to achieve desirable levels of coverage and performance. Having comparable and accurate estimates of costs is a necessary first step in planning for and implementing interventions that are of adequate scale and adequately resourced.*

Key words: Cost analysis, micronutrient interventions, noncomparability of methods, variations in methods

Introduction

Micronutrient deficiencies constitute an enormous global public health burden. Deficiencies of just three essential micronutrients—vitamin A, iron, and zinc—are estimated to result in an annual loss of 1.5 million lives and more than 51 million disability-adjusted life years (DALYs) [1].

There is an arsenal of interventions with demonstrated effectiveness in combating these deficiencies [2, 3], and substantial progress has been made [4–6]. A few high-visibility books and papers on nutrition policy have called for "repositioning nutrition as central to development" [4], labeled nutrition—and particularly child and maternal nutrition—as "a survival and development priority" [6], and even estimated the costs of "scaling up nutrition" [7]. Yet inadequate attention has been paid to the issues related to planning or managing nutrition interventions as a portfolio of programs, explicitly and deliberately taking into account their potential overlap, their potential complementarities, or their differences in cost and cost-effectiveness.

Micronutrient supplementation and commercial food fortification are the current leading strategies for addressing micronutrient malnutrition; however, they both demonstrate weaknesses in their delivery, for example, in terms of the ability of industrially fortified foods to adequately reach rural or remote populations in some countries, or the ongoing expenditures required for distribution of supplements [8–10]. Biofortification is an emerging strategy with strong

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potential for sustainable benefits. Among subpopulations with high micronutrient requirements, however (such as pregnant women and young children), its role is likely to be relatively limited by two considerations: the ability to fully eliminate the nutrient gap through consumption of staple foods [9, 10], and the amount of time that it will likely require before this strategy has adequate coverage and impact [11]. These considerations suggest that biofortification will probably be foremost a complementary strategy.

A relatively new debate is whether these micronutrient interventions could complement one another as an integrated portfolio. In such a scenario, supplementation would be provided for severe deficiency, or as an emergency response, while fortification and biofortification interventions would contribute to maintaining adequate micronutrient status and reducing moderate deficiency [9, 10, 12]. The optimal mix of interventions would probably vary to some extent by season, country context, and even among regions and population groups within a country [8, 10, 13].

The successful reduction in the global burden of disease attributable to micronutrient deficiencies suggests that micronutrient interventions are contributing to substantial global improvements in morbidity and mortality [14]. Given this progress, the need has never been greater for a portfolio approach to fine-tune the programs addressing micronutrient deficiencies. Currently interventions are managed on an ad hoc basis, with no connection between different programs addressing different micronutrient deficiencies, and with implementation falling under the ambit of different government agencies. Considering this lack of coordination, it is likely that there is already considerable overlap among programs, including possibly unexploited economies of scale and/or scope. As the diversity and coverage of these programs expand, it is increasingly important to understand their relative contributions to reducing micronutrient deficiencies. This involves making comparisons across programs; however, to date, the existing data on costs of micronutrient interventions are plagued by noncomparabilities. These relate both to the diverse activities and service delivery pathways of the interventions themselves and to differences among studies in the methods used.

Differences among micronutrient interventions

Part of the challenge in documenting and comparing micronutrient programs, particularly in terms of effectiveness and cost-effectiveness, is the vast differences in types of intervention, in terms of outcomes, target populations, coverage, service delivery pathways, implementing partners, and cost structures, among others. These differences exist even within a particular intervention type. For example, supplementation programs distributing vitamin A to children under 5 years of age are typically able to piggy-back on immunization and other integrated child health campaigns to some extent [15, 16], achieving substantial coverage rates, minimizing organizational and administrative requirements, and keeping costs relatively low [17–19]. Meanwhile, distribution of iron supplements to pregnant women commonly has been achieved through routine prenatal care services. Although the coverage of these services is commonly around 70% to 85% of pregnant women, the proportion of these women who receive and take adequate quantities of iron and folic acid tablets is likely to be less than 10% [20].

Food fortification is another increasingly prevalent mechanism for distributing micronutrients. As of mid-2013, 77 countries were fortifying some or all of their wheat flour with iron and/or folic acid, and in many instances with other nutrients [21]. Other key food vehicles, such as vegetable oil, maize flour, and sugar, are also increasingly being fortified [22–24]. Fortification commonly involves a partnership between public and private agencies, promoted via either private sector advertisements or government social marketing, and with consumers paying for the commodity through private markets. Whereas mass fortification is targeted at the general population, there are probably particular groups of vulnerable or geographically remote people who consume limited amounts of these foods.

Developing micronutrient-dense staple crops through biofortification is an emerging option for preventing micronutrient deficiencies. Unlike supplementation and commercial fortification, biofortification is a food-based intervention implemented primarily in rural areas and disseminated to consumers through market channels [9, 10, 13]. After significant initial investment in agricultural research and development, biofortification carries minimal recurrent costs and can potentially achieve high coverage, particularly in remote rural areas where both subsistence agriculture and undernutrition predominate; therefore, this strategy is anticipated to be highly cost-effective [25]. However, there are gaps in understanding the actual attributable impact and cost-effectiveness of these projects, since they are still under development and will not be widely adopted for several years [9, 10, 13]. Ex ante analyses indicate that the effectiveness and cost-effectiveness of biofortified crops in reducing micronutrient malnutrition will be context-dependent [11, 25].

Despite the importance of these specificities and distinctions between different intervention types, and their significant implications for planning, implementation, impact, and cost, they are rarely considered in general policy discussions of the costs of micronutrient programs.

Differences in methodology of costing studies

Even if it is assumed that the key characteristics of micronutrient interventions and the characteristics of the countries in which they are implemented are held constant, there may still be marked variations in a program's estimated costs. This is evident when the results of two studies of the Philippines National Vitamin A Supplementation Program are compared. One study estimated the cost to provide one person-year of protection to be US$0.28 [26], while the other estimated it to be US$339 [27]. Although the program's costs were measured in different years—1993 and 1996, respectively—that alone cannot explain variations of this order of magnitude. In this instance, much of the discrepancy was attributable to how the program was defined, which in turn was due to the different policy issues being addressed. Further, the longstanding reliance on, and continued citing of, a relatively small number of cost studies have created an illusion that there are a large number of recent studies.

Objectives of this review

This paper reviews the micronutrient cost literature, building on previous reviews [28, 29] and focusing on differences among cost studies that limit comparability. The review was undertaken to inform the costing methods for the Micronutrient Program Portfolio Study conducted by HarvestPlus. This study, funded by the Bill & Melinda Gates Foundation, aimed to assess the "optimal" micronutrient program portfolio mix in different countries, in terms of costs, coverage, and cost-effectiveness of three specific intervention types: supplementation, fortification, and biofortification. In designing these portfolio studies, it was considered important to accurately estimate the costs of these interventions in order to inform the efficient allocation of resources and financial requirements to scale up national strategies. Although this review was conducted to inform a specific study, the results are useful to researchers conducting costing studies of these three intervention types who wish to understand the implications of various methodological choices for comparability of findings.

The primary objective of this review was to improve information for decisions about resource allocation by contributing to better understanding of the variations in costs and cost structures of micronutrient interventions. While previous reviews [28, 29] have identified the importance of intervention characteristics and country context in influencing the cost estimates reported in micronutrient cost studies, this review explores these concepts in more detail, paying particular attention to methodological differences among studies. Then the review focuses on three broad methodological considerations that largely shape the process by which a study is conducted: the sources of data used, the definition of cost centers, and several specific methodological choices that significantly influence cost estimates. The review concludes with a summary of implications and recommendations for standardizing future costing studies of micronutrient interventions.

Methods

This review includes papers from both the published and the gray literature on micronutrient supplementation, fortification, and biofortification, covering three essential micronutrients: vitamin A, iron, and zinc. The discussion focuses on what have been the more studied interventions: vitamin A supplementation and fortification. In addition, the relatively limited and necessarily prospective (or ex ante) analyses of biofortification programs were reviewed. Other micronutrient interventions were not included, as these were not a focus of the study for which this review was conducted.

Studies were selected for review based on the availability of empirical data or secondary analysis (n = 130). A list of the key studies reviewed is provided in the Appendix.

For the purposes of this review, a "study" was considered to be a cost analysis of one intervention; reports or articles including cost analyses for multiple interventions (or multiple food vehicles in the case of fortification programs) were considered multiple "studies." This review is primarily focused on studies conducted since 1995, in addition to two publications that many of these studies cite [30, 31], along with the earlier core studies on which these publications were based.

More than 80% of the studies were "national" in scope, in that they analyzed interventions that were uniformly implemented throughout a country. For the purposes of this paper, and based on the lack of coverage data, the definition of a program's scope is independent of its level of coverage and is based exclusively on supply-side, structural considerations.

The biofortification cost review is based only upon the HarvestPlus phase I biofortification cost studies of 14 country–crop combinations of high-micronutrient-content varieties [25]. The discussion was limited to these studies, because the purpose of this review was to provide insights into how best to update the analysis of these same projects using methods enabling comparison with supplementation and fortification programs. These studies include only conventionally bred varieties of cassava, maize, sweet potato, beans, rice, and wheat; no genetically modified crops were included.

To date, the costs of biofortification interventions from ex ante analyses are presented in aggregate, and include the costs of developing this nascent technology. This means that the costs of biofortification are not directly comparable with the costs of supplementation and fortification, and that the specific costs and costing methods of biofortification interventions are something of a black box. Therefore, much of the discussion of noncomparabilities of these studies does not include a discussion of specific costs.

Finally, the sources of variation in cost estimates outlined in this review are not meant to be exhaustive. Other topics also warranting discussion were not addressed here because they are regarded as technical issues for cost analysis in general that are not specifically related to micronutrient interventions.

Findings: Sources of cost variations

The cost literature varies significantly in terms of what costs are included in the analysis. This primarily reflects differences in the interventions and country context, in the objectives of the studies, and how study domains are defined. There are also a variety of ways in which variations in specific costing methodologies result in variations in the estimated cost of a micronutrient program.

Intervention characteristics

The fundamental structure and technology of program implementation strongly influence program costs. The review found that while 70% of vitamin A supplementation program costs are attributable to service delivery personnel, the predominant cost of fortification programs—77% of total program costs on average—is for the fortificant itself. Moreover, among fortification and supplementation programs themselves there is significant heterogeneity. For instance, the integrated child health services package that delivers vitamin A supplements in Zambia, Child Health Week, targets 6- to 59-month-olds and lasts 7 days, whereas the Uganda program, Child Days Plus, targets infants and children from 6 months to 14 years of age and lasts a full month [18, 19].

Even for supplementation programs implemented within the same country, the cost per person reached can vary substantially, as was found, for example, in Peru, where vitamin A supplementation cost US$1.62 (in 1998 dollars) per person when it was integrated with routine Expanded Program on Immunization (EPI) services and US$2.97 per person when it was distributed through a stand-alone campaign [32]. A study of Ethiopia's Extended Outreach Strategy found that the estimated stand-alone costs of vitamin A capsule distribution were considerably greater than the costs when the distribution was added to an integrated package of campaign-delivered child health services that included deworming, nutrition screening, measles immunization, and Information Education and Communication (IEC) [33]. Integrated child health packages have also been found to enjoy economies of scope in studies of Zambia's Child Health Week and Uganda's Child Days Plus [18, 19].

There are few cost studies on iron supplementation programs. Iron supplements should be taken with a greater frequency than vitamin A supplements; these interventions therefore require a different implementation mechanism providing many more contacts than the twice-annual vitamin A programs. They are therefore not amenable to being implemented exclusively through efforts piggy-backed on National Immunization Days or Child Health Weeks. Moreover, the much greater frequency of doses means that compliance will be a more important issue (because individuals will self-administer the supplements, whereas vitamin A is usually administered by or in the presence of health professionals), as will a functioning supply chain. These concerns about compliance and frequency of dosage suggest that, compared with vitamin A programs, the costs of iron supplementation are likely to be higher, due mainly to the follow-up required for reaching pregnant women and ensuring compliance. How much more expensive they might be depends upon logistics systems requirements, delivery mechanisms, the size and composition of the target population, and the intensity of efforts for IEC and promotion of compliance, among other considerations.

The cost of fortification programs may also vary substantially due to differences in fortificant type and composition and the level of fortification. Variations in fortificant composition can increase the costs of wheat flour fortification by a factor of nine [29]. Given the high proportion of total fortification costs that is accounted for by the cost of fortificants, increases in fortification levels will produce nearly proportionate increases in the average total cost per metric ton and in the total cost of fortification programs.

Fiedler and Macdonald [34] examined the impact on costs of two different flour fortification packages. The less extensive and less costly one, labeled the "reduced package," consisted of iron, folic acid, and vitamin B_{12}. The "expanded package" consisted of these same three micronutrients in addition to zinc and vitamins B_1, B_2, B_3, B_6, and A. The expanded fortification package cost approximately twice as much per ton of food as the reduced package in any given country.

The type of fortificant used also accounts for differences in fortification costs. In the case of iron, ferrous fumarate is often used. However, the bioavailability of ferrous fumarate is compromised in countries with diets high in phytates. Sodium iron ethylenediaminetetraacetate (NaFeEDTA), a commonly used and more bioavailable form of iron, costs roughly 20% more [35].*

Even the cost of the same fortificant formulation can

* Recommending use of more costly fortificants raises concerns from private industry; this has been a key stumbling block to introducing fortification. To effectively discuss prospects for fortification with industry representatives, it is essential to have greater specificity about costs.

vary within a country. A Kenyan study of three maize millers found that prices of the identical maize flour formulation varied by 50% and resulted in differences in the incremental cost per metric ton of nearly one-third [36].

Costs also vary considerably by food vehicle. A Ugandan study found that while the same percentage of the population ate commercially produced sugar and vegetable oil, vitamin A fortification of sugar would cost the private sector US$2.6 million per year, 4.8 times more than vitamin A fortification of oil would cost the oil industry [37]. Most of this difference in cost was attributable to the different vitamin A compounds used to fortify these foods. Moreover, Fiedler and Macdonald [34] found that for each of the three most common food vehicles (wheat flour, sugar, and vegetable oil), the cost per ton of fortified food was inversely related to plant size, being highest in the smallest plants and lowest in the largest plants. For example, the incremental cost of vitamin A fortification per metric ton of food for an average large-sized flour plant was 57% of the cost for a small-sized plant.

Country context

The cost of any given type of micronutrient supplementation program is also likely to reflect a number of country-specific factors. For example, the relationship between supplementation program coverage and costs reflects a number of characteristics of the healthcare delivery system, including the composition, size, and distribution of its infrastructure. In countries with high population densities, economies of scale may yield a low unit cost per beneficiary. Depending on country population characteristics and distribution, achieving adequate coverage to impact child mortality will typically require expanding into increasingly remote populations, and the marginal costs per beneficiary may become prohibitive [38]. As Horton [39] notes, in countries such as Bangladesh and Cambodia and in parts of India, Pakistan, Laos, and Nepal, where the health infrastructure is less developed—or in the extreme case, where there is no functional health system—the costs of supplementation per beneficiary are likely to be significantly higher.

Further, demand-side factors, such as a population's knowledge of and access to programs, can affect the denominator of the cost measure (i.e., the cost per beneficiary) and may be a key reason for variations across studies [29].

In one review, country-specific variables were found to influence cost per death and DALY averted of vitamin A supplementation programs, including program coverage, the number of doses delivered, and the underlying level of mortality [17]. Estimates of mortality reduction resulting from vitamin A supplementation in countries with high prevalence rates of vitamin A deficiency ranged from 23% to 30%. A higher reduction in mortality results in a lower estimated cost per death averted and per DALY averted. The mortality reductions, however, were also conditional upon minimal levels of coverage of the program being achieved, with estimated coverage ranging from 70% to 85% (again in "high"-prevalence countries) being essential in order to capture the full impact on mortality. Downplaying or ignoring this conditionality, or assuming the rate of coverage is high, reduces the level of estimated cost–impact measures, making vitamin A supplementation programs a more attractive investment.

Several studies have captured country-level cost variations in different ways, including accounting for differences in population density and transportation costs [27, 40, 41]. A study in Nepal developed separate estimates for mountain, *terai* (lowland), and hill districts and found the costs of supplementation for these three regions to vary by as much as 43% [40, 41]. A study in South Africa accounted for intracountry cost differences by using state-specific Ministry of Health coverage measures in calculating cost outcomes [42]. As a result, the estimated coverage of the supplementation program varied across states from 58% to 88%, with a national average of 74%. State-level cost estimates are valuable and relevant for state-specific programming and budgeting in decentralized public health systems.

Given the high proportion of supplementation program costs represented by personnel, a country's labor capacity and wages are an important determinant of program costs. Countries in which the major program-implementing agency—usually the Ministry of Health—has especially low salaries will have lower than "average" costs. As such, cost estimates coming from these programs may be artificially low and misleading for budgeting in other country contexts. One study found the average healthcare worker's salary in Ethiopia (US$600) to be only 22% of the sub-Saharan Africa regional average [33]. Using the cost estimates from Ethiopia would significantly underestimate the costs of a comparable program in another country.

There are several country-specific factors that influence fortification program costs. These include food consumption patterns, particularly relative consumption of purchased food compared with own production; industrial structure, including import duties on fortificants, and processing and distribution systems; and the cost of government monitoring and regulation of industry [28, 29]. In many studies, the costs of government regulation are ignored, thus resulting in underestimation of the costs of fortification compared with alternative interventions.

Data sources

The source of data, for measures both of program costs and of effectiveness, determines to a large extent the methodology used in a study.

Cost data

Two common sources of cost data are a program's accounting records and estimates developed with an "ingredients approach" using unit costs and quantities of program inputs [43].

The accounting-based approach is limited by the comprehensiveness of the accounting system, and there is often a need to augment the cost-accounting data with additional information to capture all resources. Resources that are unlikely to be recorded in a program's financial accounting systems include in-kind contributions, such as micronutrient supplements or fortificants donated by private or international agencies. Other examples of "off-budget" costs include resources shared among programs, resources contributed by partner organizations, and opportunity costs of capital, personnel, and program beneficiaries. Opportunity costs can represent a significant proportion of total program resource use, particularly for programs relying on volunteer labor. A study in the Philippines estimated that 30% of the costs of a vitamin A supplementation program were attributable to volunteer labor [27]. Studies excluding an estimate of these economic costs may therefore report artificially low cost estimates, which could mislead other countries planning to implement similar programs.

While the accounting approach could be considered a top-down methodology using existing data to build cost estimates, the ingredients approach is a bottom-up methodology relying primarily on data obtained from interviews to identify all inputs used to produce a particular output. The ingredients approach provides a mechanism for standardizing common program components across countries, thereby enabling cross-country and interregional comparisons, and provides opportunities for identifying how the relationships between inputs and outputs may be modified to reduce costs, increase outputs, or both. In the ingredients approach, the cost analysis is built up from the sum of its parts, using costing algorithms with the cost and quantity of various program inputs to produce transparent estimates. This method was used in an analysis of Ethiopia's Enhanced Outreach Strategy, to develop regional unit costs at different administrative levels, providing insights into the extent of interregional cost variation [33].

When building cost estimates from scratch, surveys are a useful tool for developing a detailed understanding of how a program functions and how its performance and costs vary across the different levels of the implementing organization. However, survey data are not always used for better understanding programs. For instance, three connected vitamin A supplementation program studies in Ghana, Zambia, and Tanzania were based on nationally representative district-level survey samples; however, the studies then simply developed a national average based on that sample [44–46]. The opportunity was lost to better understand how costs were affected by variations in urban–rural population ratios, population density, ecology, topography, or accessibility, and the potential was not fully realized for developing cost estimates that could provide a more accurate tool for allocating program resources. Some common practices compromising the potential level of precision of cost estimates attained from survey data related to the way in which surveys were structured, how the sample was identified, how the data were analyzed, and how the cost estimates based on them were extrapolated to the country level.

Effectiveness data

The large variety of cost outcomes reported in the micronutrient intervention cost studies can themselves contribute to noncomparabilities. "Cost outcomes" are a common way to present the results of an economic analysis, often calculated as cost per program outcome or impact. Studies lacking data on program effectiveness often present the total program cost or the cost per beneficiary [29].

Supplementation programs commonly report the cost per beneficiary. When coverage data are not available, data may be used from Demographic and Health Surveys, such as the proportion of children whose mothers reported the child received a vitamin A supplement in the past 6 months. Two other common approaches using program data are the number of persons dosed, as reported in tally sheets maintained by the service delivery staff; or a proxy measure, such as the number of capsules (or tablets or doses of syrup) distributed. These per capita measures often vary depending on whether the data come from program-based or population-based surveys, with program data reporting substantially higher coverage rates [47, 48].

This variation also relates to the nature of the implementing agency, since nongovernmental organizations (NGOs) may rely on program data while governments may rely more on population-based surveys. Cost studies from NGO programs yield costs per beneficiary that are between one-quarter and one-third higher than those for public sector programs [28, 29]. In addition to possible differences in methods and contextual factors, this higher cost may reflect the facts that NGOs may have better-paid staff, serve more remote areas, or have more comprehensive documentation of program inputs.

Fortification programs commonly report the incremental cost per metric ton of the food vehicle, the proportion of the increase in a the retail price of a food due to its fortification, and the cost per person per year [28, 29]. Because of the limited availability of individual food consumption data, most fortification study cost measures are devoid of program impact denominators, relying instead on unconditional national per capita consumption data. This practice renders them subject to even greater uncertainty than supplementation program measures, in terms of their validity and reliability in measuring changes in micronutrient status. Food consumption and household expenditure surveys have been used to measure individual-specific fortification impacts in only two countries—South Africa and the Philippines [27, 49]—to estimate the cost per micronutrient-deficient person reached and the cost per micronutrient-deficient person whose deficiency is eliminated by fortification. Recent methodological advances have used Household Consumption and Expenditure Survey (HCES) data, combining the quantity of different food types "apparently consumed" with the nutrient contents of the foods to estimate conditional consumption levels, to model usual intake, deficiencies, and impacts of proposed programs [50] (personal communication, Z. Rambeloson, monitoring and evaluation expert of A2Z, the USAID Micronutrient Project, 2010). This is an area requiring further investigation to improve understanding and measurement of the impact and costs of fortification and biofortification programs.

Other common effectiveness measures that are found in the micronutrient program cost literature are the cost per life saved (death averted) and cost per DALY saved. Several methodologies have been used to estimate the impact of vitamin A supplementation programs in terms of lives or DALYs saved, usually involving assumptions about mortality reductions achievable given different coverage rates [51–53].* As discussed previously, assumptions about the number of deaths averted strongly affect the number of DALYs saved and therefore the cost per DALY. The 2010 update of the Global Burden of Disease (GBD) study demonstrated significant gains in life expectancy, with deaths among children under 5 years of age declining by nearly 60% since 1970 [54]. The 2013 *Lancet* Series on Maternal and Child Nutrition did not use the updated GBD estimates [55]. Their estimates of deaths attributable to micronutrient deficiencies were lower than the estimates in the previous 2008 Series, but higher than those in the 2010 GBD update. The authors postulated that this reduction in mortality was due in part to the effectiveness of large-scale supplementation programs, along with general improvement in nutritional status and treatment of illness. The changes in underlying mortality risks will impact future cost estimates of micronutrient programs, and by decreasing the denominator of cost measures, will necessarily show a decrease in the relative cost-effectiveness of these programs.

*UNICEF. Note for the record: Calculation of the number of lives saved with vitamin A supplementation. Unpublished memorandum and Excel spreadsheet. New York: UNICEF, 2001.

Definition of cost centers

One of the first steps in undertaking a cost analysis is to define the study's "cost centers," which organize and categorize the resources used in a program. How they are defined is both influenced by, and influences, the choice of methodology used in the study, particularly the data source. The two most common sources of cost data, discussed previously, also characterize the two most common ways of categorizing costs, namely the cost accounting-based approach and the ingredients approach.

Cost centers in the cost accounting-based approach are generally defined in a manner identical to the implementing agency's existing cost accounting system, in terms of the inputs (objects of expenditure) tracked within that system. These include personnel, pharmaceutical supplies, medical supplies, office supplies, equipment, basic services, etc.

Unit costs estimated with the ingredients approach can be classified in a variety of ways, including by input category, intervention activity, or organizational level [43]. Several studies have combined an ingredients approach with an activity-based costing (ABC) methodology [18, 19, 27], wherein algorithms are specified for all major program activities. These algorithms are useful for planning and budgeting and can be used dynamically to envision the cost of program scale-up.

Biofortification program cost structures

The costs of biofortification can be broken down into several distinct cost centers; the categories selected influence the scope of costs included in the analysis, with implications for cost levels. The full life cycle of a biofortified crop can be conceptualized as consisting of four distinct, but overlapping, phases:

Basic research and development (R&D), during which several promising parent lines are developed that are used to produce lines for several countries;

Adaptive breeding of the parent line to better provide for the individual country's needs;

Release and dissemination, consisting of the incremental costs for seed systems to release, multiply, and distribute the biofortified variety, nutrition education, and behavior change communication; and

Maintenance breeding to ensure that the enhanced micronutrient and agronomic characteristics of the biofortified hybrid are maintained over time.

The average share of each of the four components has varied from 17% for maintenance breeding, to 22% for R&D, 25% for adaptive breeding, and 35% for release and dissemination. The costs of each of the four components of the biofortification projects vary substantially, with those for release and dissemination having by far the largest variance. The lowest-cost release and dissemination effort was that of the high-iron and high-zinc beans project in Honduras, which was estimated to cost US$328,000, compared with the provitamin A cassava project of Nigeria, which was estimated at more than US$21 million, nearly 70 times larger.

Inclusion of R&D costs in program cost estimates is somewhat controversial in that these costs may be conceptualized as occurring prior to implementation. This would complicate comparisons with other interventions that have been developed and are ready to be introduced or scaled up. However, simple exclusion of R&D costs does not necessarily promote comparisons with other interventions, due to the need for adaptive breeding that fits country-specific contexts and regulations.

In the studies reviewed, the methods used to estimate these costs varied by component. The R&D costs were based on historical R&D estimates from crop-specific budgets. The other three components, comprising 78% of total costs, were based on country- and crop-specific expert opinion. While the general comparability of the methodologies that these 14 different individuals used to develop the estimates is unknown, there is considerable room for variation, making direct comparisons difficult.

As with fortification and supplementation programs, there are multiple potential sources of variation in the level and composition of costs across the biofortification cost studies. These include variations in country-specific characteristics, such as the prices of nontradable inputs like researchers' salaries and media, the size of the populations they might be expected to reach (both of consumers and of farmers), and the nature of the nutrition education and behavior change communication in the dissemination component.

Choice of methodology and differences among methods

This section summarizes several methodological choices that have had implications for the cost levels and outcomes reported in the micronutrient cost literature.

Analytical perspective: Whose costs to include

Depending on its objectives, an analysis can be conducted from the perspective of implementing institutions or it can provide more comprehensive estimates of the costs to society as a whole [56]. Study objectives and perspectives influence which costs are appropriate to include.

The analytical perspective is likely to vary by intervention type, study objective, and how the domain of the costing study is defined. Fortification studies commonly include costs to private industry, whereas supplementation studies include costs to government. It is much less common for studies to take a societal perspective. However, assessing broader program costs, including the costs to program participants, can provide insight into potential users' ease of participating in a program, which affects program participation and coverage, and thereby the average cost per beneficiary.

Many of the costs of supplementation programs in particular are relatively fixed (i.e., they do not change or do not change in direct proportion to the increase in output or persons served); therefore, increasing program participation rates generally means decreasing the program's average cost per beneficiary. However, whether a program has a low cost per beneficiary may change when costs incurred by beneficiary households themselves are included. Existing supplementation studies investigating household costs have found them to range widely from 79% of an iron program's total costs to 65% of a vitamin A program's total costs, down to 18% of the total costs of a facility-based strategy to prevent malaria and anemia [57–59].

Cost studies of fortification programs vary significantly in the methods used and the type of costs included in the estimates, with private industry costs estimated more precisely than government costs [28, 29]. There are several reasons for the differential rates of precision in the studies reviewed. First, the costs of the government components of programs—constructing the policy environment, marketing and education efforts, quality assurance monitoring, and nutrition surveillance—are likely to be subject to considerable variation because they commonly reflect anticipated budgetary allocations. Second, some countries only added to the responsibilities of their existing agencies, whereas other countries needed to establish such agencies "from scratch." Thus, the costs of marketing and education vary from 1% in the Indonesian and Pakistani wheat flour fortification proposals to 14% in the cases of China and Thailand [60]. Lastly, private industry representatives were motivated to provide accurate estimates for costing exercises to avoid putting their industries at financial risk by the cost estimates if their respective governments opted to implement these programs.

Price adjustments and price indices

The literature contains a number of different cost measures that require adjustments for analysis. For example, data are not always adjusted for changes in currency value. When the literature is reviewed, the year in which the original study was conducted—as opposed to the year of publication—is often not reported. Given that it generally takes a year or two for studies to be reported or published, and the not uncommon practice of basing studies on program or consumption data that are several years old, variation in the value of the currency is a potential source of significant variation in reported cost results. For instance, the 1987 SCN State of the Art Review used data from an Indonesian vitamin A supplementation program from 1975 [61], and a 1999 publication of a program study in Tanzania was based on 1992 data [62].

Further, it is unclear whether adjustments in currency value are properly made. The common practice is to use the consumer price index (CPI) or a gross domestic product (GDP) or gross national product (GNP) deflator, which, depending upon the program's cost structure, may result in substantial over- or underadjustment. A vitamin A study in the Philippines conducted a sensitivity analysis of the use of a GDP deflator, a CPI deflator, and a program-specific adjustment index that was based on changes in the major cost elements of the program [27]. The program-specific adjustment consisted of four components: the imputed wage of volunteers, the average wage increase of Ministry of Health personnel, change in the price of vitamin A capsules owing to the devaluation of Filipino currency, and the remaining 25% of costs adjusted by the CPI. The analysis found that the more circumspect approach resulted in a doubling of the adjustment of the vitamin A supplementation program costs: the estimated increase in costs was 15%, compared with 7% with the use of either the CPI or the GDP deflator. This is a topic that merits more attention, especially given that the costs of micronutrient interventions are so highly concentrated in a few inputs, with personnel and fortificants accounting for a large proportion of the total costs of supplementation and fortification programs, respectively [28, 29].

Time domain differences

The review contained two distinct types of cost studies: roughly 60% of the studies were "prospective" or "ex ante" studies modeling costs of hypothetical programs, and 40% were "retrospective," estimating costs of existing programs. The type of study varied by program, with all of the supplementation cost studies being retrospective, the fortification studies being mainly prospective, and the biofortification studies being ex ante, since these technologies have not yet been released. These differences reflect the different motivations for conducting these studies: to promote or raise funds for an existing supplementation program, to provide a detailed accounting to private sector partners of potential fortification programs, or to demonstrate the attractiveness of biofortification programs as social investments.

These different study types result in cost estimates of varying degrees of certainty and precision; therefore, systematic differences in study type across the three micronutrient programs reduce the direct comparability of their cost estimates. Several characteristics of ex ante studies make them particularly likely to generate estimates with greater uncertainty and less precision. First, they are based on assumptions about program implementation. Second, different studies include different costs, depending on whether the technology has been developed (commonly used for fortification programs) or is still undergoing R&D (commonly used for biofortification programs).

Summary of implications and recommendations

This review has shown that there are significant variations in cost estimates of micronutrient interventions and that the sources of these variations are numerous. The content of cost estimates and approaches to calculating them vary depending upon a number of interrelated factors, including:

- The specific characteristics of the country
- The specific characteristics of the program and how it is implemented
- The purpose for which costs are being estimated
- Which costs are included in the estimates (private sector, public sector, households)
- The audience
- The perspective of the analysis (i.e., societal versus institutional)
- The study domain (what is included in the cost analysis)
- The methodological approach adopted
- The time available for carrying out the study
- The resources available for undertaking the study
- The source(s) of data.

Taking into account the methods used in the studies reviewed for this paper, there are several implications for improving the design of micronutrient cost studies. The following recommendations can be used to ensure that cost estimates are as precise as possible and that the results are as comprehensive and as comparable as possible across interventions within countries as well as across countries:

- Calculate the total (economic) cost along with additional budgetary requirements, to allow program managers to better understand resource requirements for budgeting purposes. Since micronutrient programs often piggy-back on existing programs, the important measure for decision makers is the incremental cost that the micronutrient intervention will require, rather than the total costs. Still, so as not to be vulnerable to charges of trying to minimize costs—especially in the case of supplementation programs that are delivered as part of a multiintervention package—it is important to develop the methodology in such a manner as to enable presentation of the incremental costs of the micronutrient supplementation, along with the cost of the micronutrient program component alone, as if it were a stand-alone intervention.

- » When comparing interventions, use the same basic costing approach, ensuring that the types of costs compared are the same.
- » Given that these interventions are commonly piggybacked on other existing programs, some shared program elements should be addressed when developing cost estimates for each of the intervention types:
  - – *Identifying and prorating shared resources or inputs:* These are likely to be important, and the appropriate portion of these inputs that are used in the micronutrient intervention should be identified and used to attribute a share of them to the program.
  - – *Off-budget items:* It is essential to include these to estimate the intervention's "full" or "economic" costs. Given the differential importance of off-budget items by type of micronutrient program, other things being equal, not including them would make supplementation interventions look substantially less costly than they are.
- » The costs included should be as comprehensive as possible. Where community costs are likely to contribute significantly to total program resource use, a societal perspective should be applied. Although taking the societal perspective provides useful information informing program utilization, it also consumes additional time and resources. Given resource constraints in each specific situation, it is essential to weigh the expected costs and potential benefits that are likely to result from alternative study designs in order to best strike this balance. This requires being cognizant of the full range of program costs from the onset of study design and identifying what are potentially important policy issues that need to be addressed so that budget constraints do not end up undermining the usefulness of the study.
- » Where applicable, ensure that volunteer labor time is noted and valuated, both to ensure comparability across countries and to better understand implementation, an important source of variation in estimated costs. Ensure that relevant public sector costs are included, especially monitoring and regulatory costs for fortification programs, which are often neglected. Using cost centers that are composed of the major activities of a program can aid in capturing all program inputs in an analysis.
- » Much of the variation in costs in the literature is attributable to country-specific characteristics. Therefore, studies that compare program costs within a country are much more likely to be precise than ones making across-country comparisons. Conduct comparative analyses within the same country to enable controlling for as many variables as possible and thereby better ensure the comparability of the costs and other findings. Finally, because costs are so influenced by contextual factors, it is advisable to report a series of metrics and to describe programs and country contexts in much greater detail than is currently the norm.
- » Given all of the critical assumptions involved in estimating DALYs and how these influence the cost outcomes of a study, it is advisable to present multiple cost outcomes (e.g., cost per outcome, cost per impact, or even cost per beneficiary). This serves at least two purposes. First, it facilitates triangulation with cost per DALY. If an intervention is highly cost-effective per DALY averted, this could be due in part to assumptions of high mortality in untreated cases; if the cost per beneficiary or per case recovered is high, this provides information on the general affordability of the program. Second, although cost per DALY is useful to policy makers for decision-making and prioritizing interventions for reduction of morbidity and mortality, this measure does not provide guidance on how many resources (or what kinds of resources) are needed for each beneficiary entering the program. Providing a cost measure per disease outcome (e.g., cost per case of anemia or episode of diarrhea averted) further enables comparison of the intervention with others addressing this same specific outcome.
- » It essential to carefully develop cost estimates and conduct sensitivity analyses on the costs of key inputs (including micronutrient fortificants or premixes) and other measurements (including annual coverage costs and cost per DALY). Further, both cost analyses and the methods for adjusting costs should be as input- or goods-specific as possible so as to better ensure the accuracy of estimated costs over time.
- » Undertaking small-scale surveys to collect information is useful to better understand the determinants of costs and thereby variations in costs in order to construct more accurate cost estimates. Developing and implementing a study that allows for this type of variation requires more effort and resources, and whether it is worthwhile depends in part on the study objective and how the results will be used. However, when studies have been designed to allow for variations in cost structures according to the level of the program, they have generally found significant variation.

Conclusions

The methodological variations and noncomparabilities outlined in this review do much more than limit the ability to make direct comparisons of costing studies; they carry important implications for adoption of interventions in countries suffering from deficiencies in key micronutrients. Given the indications of improvement in the global burden of micronutrient deficiencies, it is important to focus on streamlining implementation of these interventions. There is a need to better understand not only which programs should be implemented, where, and when, but also *how*, in terms of what level of support (both financial and otherwise) they will require to achieve specified levels of coverage and performance. Having comparable and accurate estimates of costs is a necessary first step in creating an integrated portfolio of interventions that are of adequate scale and adequately resourced for effective implementation.

Acknowledgments

The authors gratefully acknowledge the support of the Bill & Melinda Gates Foundation's Nutrition and Economic Research Support to Harvest Plus for Grand Challenge 9 Projects Grant OPP52013, and thank Ekin Birol, Purnima Menon and Carol Levin for helpful comments on an earlier version.

End note

Supplementary materials showing additional analyses are available upon request.

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Assessing alternative industrial fortification portfolios: A Bangladesh case study

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Abstract

Background. *Approximately 1.2 million disability-adjusted life years (DALYs) are lost annually in Bangladesh due to deficiencies of vitamin A, iron, and zinc.*

Objective. *To provide evidence on the coverage, costs, and cost-effectiveness of alternative fortification interventions to inform nutrition policy-making in Bangladesh.*

Methods. *Combining the 2005 Bangladesh Household Income and Expenditure Survey with a Bangladesh food composition table, apparent intakes of energy, vitamin A, iron, and zinc, and the coverage and apparent consumption levels of fortifiable vegetable oil and wheat flour are estimated. Assuming that fortification levels are those established in official regulations, the costs and cost-effectiveness of the two vehicles are assessed independently and as a two-vehicle portfolio.*

Results. *Vegetable oil has a coverage rate of 76% and is estimated to reduce the prevalence of inadequate vitamin A intake from 83% to 64%. The coverage of wheat flour is high (65%), but the small quantities consumed result in small reductions in the prevalence of inadequate intakes: 1.5 percentage points for iron, less than 1 for zinc, and 2 for vitamin A, while reducing average Estimated Average Requirement (EAR) gaps by 8%, 9%, and 15%, respectively. The most cost-effective 10-micronutrient wheat flour formulation costs US$1.91 million annually, saving 129,212 DALYs at a unit cost of US$14.75. Fortifying vegetable oil would cost US$1.27 million annually, saving 406,877 DALYs at an average cost of US$3.25. Sensitivity analyses explore various permutations of the wheat flour formulation. Divisional variations in coverage, cost, and impact are examined.*

Conclusions. *Vegetable oil fortification is the most cost-effective of the three portfolios analyzed, but all three are very cost-effective options for Bangladesh.*

Key words: Bangladesh, fortification, Household Consumption and Expenditure Survey (HCES), household surveys, micronutrients, nutrition, nutrition policy, portfolio

Introduction

"Past experience with strategies directed toward correction of iron, vitamin A and iodine deficiencies demonstrates that there is a "tool-chest" of potentially effective, complementary interventions … Experience suggests that it is the selection and adoption of the right mix of tools for a particular country or regional setting that can ensure success [1]."

The above statement was among the key findings of the US Institute of Medicine in its landmark 1998 report *Prevention of Micronutrient Deficiencies: Tools for Policymakers and Public Health Workers*. Sixteen years later, although the language has changed and there is growing talk about the "optimal program portfolio mix," there remains a paucity of studies that have analyzed more than one dimension of more than a single micronutrient program intervention: stand-alone analyses of single micronutrient program interventions—be they supplementation, fortification, biofortification, or behavior change communication—continue to overwhelmingly dominate the literature.

The requisite data for investigating the "optimal" portfolio remain scant. So too, therefore, does the portfolio optimization evidence base. One of the reasons for this dearth of data and evidence is that the individual programs themselves are strikingly different in terms

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of target populations, implementing agencies, public and private sector roles, the nature of their technology, the extent to which they are government implemented versus market based, the size and nature of the costs, their sources of financing, the incidence of costs, and, more generally, the nature and the cost of behavioral change that is required to become a participant in or otherwise benefit from a program. These many noncomparabilities complicate the analytics substantially [2] and are a major reason why there have been only a handful of comparative analyses of micronutrient interventions [3–8].

The specific micronutrients included in the intervention and the nature of the benefits are additional sources of noncomparability. How, for instance, do we compare a program that primarily reduces morbidity with one that primarily reduces mortality? How do we compare the multiple benefits of wheat flour fortification with the vitamin A–only impact of oil fortification? How does one compare the impacts of programs that are focused on different specific micronutrients? For example, how does one compare the impacts of an iron intervention, which primarily decreases morbidity by reducing cognitive losses and physical stamina; a zinc intervention, which also reduces morbidity but acts primarily by reducing stunting; and a vitamin A intervention, which has a more mortality-concentrated impact? For the past two decades, the most common method for analytically bridging the heterogeneity of health and nutrition in measuring disease burden and program impacts has been disability-adjusted life years (DALYs) [9, 10].

DALYs are a particularly useful tool for assessing policy alternatives because they enable diverse health intervention impacts—including temporary and permanent morbidity and mortality—to be combined into a single metric, thereby enabling more direct comparisons of the relative importance or burden of different conditions and diseases, and, by calculating changes in pre- and postprogram intervention disease burdens, they provide a means for comparative analyses of the effectiveness of a wide variety of health interventions. When DALYs are combined with information on health intervention costs, they provide a measure of cost-effectiveness, a powerful criterion for prioritizing health interventions [11].

DALYs, however, have shortcomings and limitations. For some interventions, DALYs provide only a partial accounting of an intervention's health impacts. For others, there does not exist a general consensus about the adequacy of the scientific basis of estimates of the morbidity or mortality impacts of interventions with which to estimate DALYs. As a result, there are DALY algorithms for vitamin A, iron, and zinc, but not for most other micronutrients. Moreover, for some interventions, there are widely accepted morbidity or mortality estimates only for specific subpopulations. That is the case, for instance, with many nutritional disorders: generally there are estimates for children under 5 years of age and women of childbearing age (in particular, pregnant or lactating women), but not for the rest of the population. Furthermore, the impact measures of different nutrition estimates are not static. They have evolved as the science on which they are based has evolved; witness the reconsideration and imminent reversal of the International Zinc Nutrition Consultative Group (IZiNCG) 2004 revisions made in the US Institute of Medicine's zinc standards for young children [12–15]. These limitations make for less than ideal comparisons.

Despite their shortcomings, DALYs remain the single most commonly used such tool. A recent paper produced as part of the comprehensive review of the nutrition evidence base by the Sackler Institute for Nutrition Science notes: "It is now fairly standard that new nutrition interventions provide estimates of cost-effectiveness, in order to ascertain whether they should be included in national (and international) strategies" [16]. Clearly, DALYs are not a panacea for addressing the host of nutrition program noncomparabilities; there remain important noncomparabilities that need to be borne in mind in comparing and assessing alternative program interventions.

Overcoming the many noncomparabilities requires analyses of the costs, coverage, and impacts of interventions from a common, more inclusive, and more comprehensive societal perspective. Such an approach requires a database that enables these diverse measures to be compared, and it requires employing common methodologies for measuring costs, coverage, and impact. Those databases do not exist. They have to be created.

An even more fundamental constraint has been the general lack of nationally representative data with which to "simply" measure micronutrient intakes. Only a handful of countries in the world have nationally representative dietary assessment data that were produced using what nutritionists generally regard as the preferred food consumption methodologies, i.e., observed-weighed food records (OWFRs) or 24-hour recall (24-HR) surveys. For the vast majority of middle- and low-income countries, these are simply too expensive, too technically challenging to conduct, and too difficult to manage on other than a small scale [17–19]. Although there has been little progress in studies of portfolio analyses, or databases with which to conduct them, the number and coverage of supplementation, fortification, and, most recently, biofortification programs have grown impressively and have contributed to growing speculation about whether all of the programs are necessary. The proliferation of programs has also raised concern about the possibility that programs in some countries may be putting individuals at risk for excess intakes.

Economic considerations also call for adopting more integrated and comprehensive analytic approaches to analyzing and managing micronutrient programs. The opportunity cost of inefficient programs is that the same resources could be implementing more, bigger, and/or better-performing nutrition programs. Improving the efficiency of micronutrient programs provides an opportunity to accelerate progress in reducing malnutrition rates. Although growth in the number and coverage of nutrition programs results at some point in overlap, overlap does not necessarily mean that programs are duplicative or obsolete. Overlap may be desirable to address issues of the seasonality of nutrient availability, or where deficiencies are severe and programs do not, individually, provide enough additional intake.

For the vast majority of countries that have little or no food consumption data, Household Consumption and Expenditure Survey (HCES)-based portfolio analysis can be a useful tool for understanding the coverage and impact of existing programs, for conducting surveillance, monitoring, and evaluation, and for prioritizing potential food vehicles and designing new initiatives [2, 20–23]. This study represents a modest addition to the nascent literature addressing these issues. It focuses on the fortification program portfolio in Bangladesh, analyzing two fortification interventions: the recently (2012) introduced vitamin A fortification of vegetable oil and a hypothetical wheat flour fortification program.

The case study context: Bangladesh

Although fortification feasibility studies have been conducted in Bangladesh for at least 30 years [24], the only mass fortification program of a staple in Bangladesh at present is the vitamin A fortification of soybean and palm oil that was introduced on a voluntary basis in February 2012. Within 6 months, the number of participating companies jumped to 16, covering an estimated 76% of Bangladesh's total vegetable oil market, that portion composed of palm and soybean oil [25].

Although efforts to fortify wheat flour have a largely shared history with the vegetable oil efforts, there remains considerable opposition to wheat flour fortification by the food company conglomerates that own the roller mills. The wheat flour fortification component of this analysis is therefore an ex ante study.

Bangladesh consumes two different types of wheat flour, *maida* and *atta*. Maida is a more highly refined, white flour, and atta is whole wheat flour. They have extraction rates of roughly 60% and 75%, respectively, which are directly related to their phytate contents.* Phytates inhibit the absorption of iron and zinc, making them less bioavailable. Other things being equal, the higher phytate content of atta reduces the impact of its added iron and zinc relative to maida.

It is also important to distinguish maida and atta flours because of the differences in the mills used to produce them, the different milling processes they use, and their different industrial structures, which condition their amenability to being fortified. The wheat milling industry of Bangladesh consists of two distinct types of flour mills: *chakkis* and roller mills. Roller mills commonly produce both maida and atta. On average, 75% of the roller mills' output is maida and 25% is atta. The traditional mills of Bangladesh are chakkis. Chakkis use stones to grind the grain, are usually powered by a small diesel engine, and have a capacity of between 0.3 and 0.8 MT per day. Roller mills have much greater capacity, using pneumatics to move the grain and cylindrical rollers to crush it. All maida is produced by roller mills, and although chakkis produce only atta, they do not produce all of the atta.

Information on the milling industry is partial and piecemeal, but a number of important trends are evident. Since the 1990s, roller mills have grown in both number and size and have come to increasingly dominate the market, as the industry has become increasingly based on imported wheat [26, 27]. A 2013 US Department of Agriculture report [28] estimates that roller mills now produce 93% of Bangladesh's commercially produced, premilled wheat flour. It is important to note that these premilled wheat flour data exclude the vast majority of the wheat flour that is produced by chakki millers. Chakkis generally do not sell premilled flour; they sell milling services, provided on demand, milling the grain brought to them by households. It is assumed that because of their large numbers, highly dispersed and unidentified locations, and rudimentary technology, flour milled by chakkis is not fortifiable.

Traditionally, the main source of vegetable oil in Bangladesh was home-grown and home-processed mustard seed. The market has changed dramatically in recent years with the rapid growth in low-priced imports, initially of soybean oil and more recently palm oil. Since 2006, Bangladesh's total annual vegetable oil market has been about 1.3 million MT, about 55% of which is food [29, 30]. Mustard-based oil now constitutes less than 10% of the total market, while soybean oil constitutes 15% to 20%, palm constitutes 70%, and all other sources account for the rest [30, 31]. Looking more specifically at the composition of oils in the Bangladesh food supply, the shares of soybean and especially mustard or rapeseed oil have been eroded significantly in recent years. They now average about 35% and 15%, respectively, while palm has surged, and now constitutes about half of the entire market.

* The extraction rate is the amount of flour produced from milling grain and is usually expressed as a percentage.

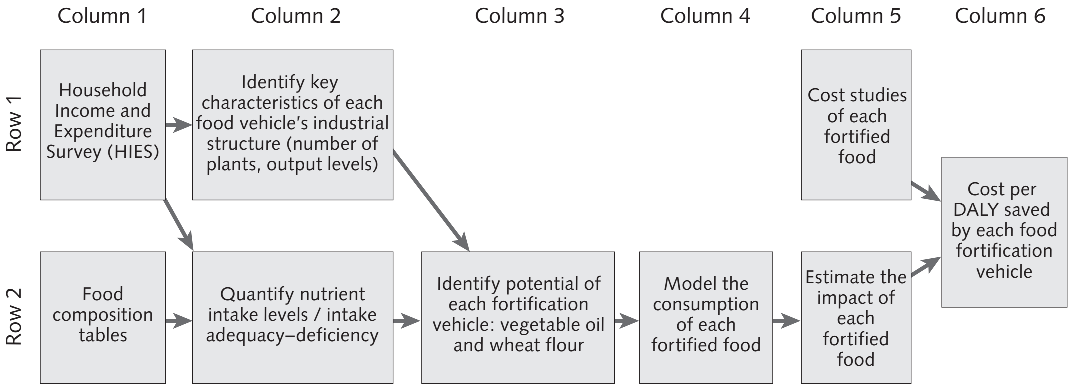

FIG. 1. Estimating the cost coverage, impact, and cost-effectiveness of a fortification program portflio, Bangladesh
DALY, disability-adjusted life year

Methods

The primary data source for this study was the Bangladesh 2005 Household Income and Expenditures Survey (HIES), a multipurpose survey conducted by the Bangladesh Bureau of Statistics (BBS). Bangladesh began conducting HIES in 1972. This fourteenth HIES round incorporated a multistage stratified random sample based on the 2001 population census. A total of 10,080 households were included in the sample. Demographic information was collected on each of the 48,969 household members. Sample weights, adjusted for nonresponse, were included in the database and were used to determine total population estimates of the numbers of households and household members. The survey provides reliable estimates at the national level and at the level of Bangladesh's seven divisions [32]

Figure 1 presents an overview of the approach used in analyzing Bangladesh's fortification portfolio [2]. The 2005 HIES Consumption Module contains 134 food items. Households reported their food consumption and acquisition using seven consecutive 2-day recalls. Households identified the quantity, value, and source (i.e., purchases, in-kind wage, own production, gifted, and other) of each food item for each day during the 14-day reporting period. We combined these data (row 1, column 1) with energy and nutrient information from food composition tables (row 2, column 1) created for this analysis to estimate the household's total "apparent consumption" at baseline and its "apparent nutrient intake levels." In addition to the specific foods identified in the 134-item food list, each of the 13 general food categories contained an entry called "Other." For these "other" categories (e.g., "other fruits," "other vegetables"), energy and nutrient values were estimated by taking the average of all other items included in the food composition table within the general food category. The HIES also includes several "dining out" meals and differentiates them by their primary ingredient (e.g., rice). Typical recipes were used to estimate the energy and nutrient composition of these meals [33].

We assumed that food that was purchased during the 14-day reference period was entirely consumed during that period and that no other food was consumed (e.g., from food stores purchased during an earlier period).* Adjustments were made for the edible portion of foods, but not for any waste or loss. We refer to the HIES-based estimates of food consumed as "apparent food consumption." "Usual daily intake" of vitamin A was calculated as the mean daily intake of food over the 14-day period.

The HIES reports food consumption data for the entire household, not for individual members. Making inferences about individual household members' nutrient intakes requires making an assumption about the intrahousehold distribution of the household's available food. We assume that all household food is distributed among its members in direct proportion to each member's share of the household's total adult male consumption equivalents (ACEs) [37]. ACE was calculated as the ratio of the energy requirement of an individual of a particular age and sex with a medium physical activity level to the energy requirement of an adult male aged 18 to 30 years.**

We used a cut-point method to calculate the prevalence of inadequate intakes of vitamin A and zinc, and the probability method to calculate the prevalence of

* The issue of stocks, the magnitude of their distortion of "usual intake" estimates, and their relationship to the length of the recall period are discussed in Fiedler [34] and reviewed and empirically investigated in Gibson and Kim [35] and Beegle et al. [36].

** The HIES lacked information about the pregnancy and lactation status of women. In our analysis, therefore, we treat all women as nonpregnant and nonlactating.

inadequate iron intake. For zinc, we used the IZiNCG standards [12] for women 19 years of age or older with the recently recommended update of 2.97 mg per day [14]. For all other persons, the US Institute of Medicine [13] zinc standards were used. The Estimated Average Requirement (EAR) standards for iron and vitamin A used for all persons were those of the US Institute of Medicine [13].

We estimated the coverage and quantities of each food vehicle apparently consumed (**fig. 1,** column 3). It was assumed that only the portion of a food item that was purchased was fortified (that which was consumed from home production or received without payment, in kind or free of charge, or gifted was not fortified). We estimated that the additional nutrient intake (**fig. 1,** column 4) from each fortifiable food due to consumption of a particular food fortification vehicle was equal to the individual's estimated "usual intake" of the food in question, multiplied by the Ministry of Industry, Bangladesh Standards and Testing Institution (BSTI) fortification standards (**box 1**). It is assumed that all of the fortifiable food item that was purchased was fortified and that the companies producing the fortification vehicles were compliant with the fortification regulations. It was assumed that the bioavailability of iron was 5%. The bioavailability of zinc was allowed to change with age and sex and assumed an unrefined cereal-based diet based on IZiNCG standards [13]. Fortification program impacts were modeled as the change in nutrient intake status (i.e., baseline nutrient intake level minus endline intake level and baseline EAR gap minus endline EAR gap) and changes in DALYs (column 5, row 2).

Functional outcomes associated with inadequate micronutrient intakes were used to estimate the number of DALYs attributed to the inadequacy of each micronutrient. The counterfactual approach calculated impact as the difference in the number of DALYs attributable to zinc, vitamin A, and iron deficiencies before and after the introduction of fortification. The baseline level of DALYs is estimated from the current burden of these micronutrient deficiencies, calculated from reported incidence rates of clinical outcomes associated with each deficiency among target populations as well as other comparative risk assessment-based estimates. The endline estimates of inadequate intakes are used to develop new estimates of the number and percentage of persons who have nutrient deficiencies by adjusting and calculating new incidence rates of zinc-, vitamin A–, and iron-related health outcomes. These new incidence rates of zinc-, vitamin A–, and iron-related health outcomes are used to estimate the number of DALYs lost after the implementation of fortification. The difference between the baseline and endline estimates is the number of DALYs saved (or averted) by the introduction of fortification.

The estimation of the DALYs assumes that persons whose intake gaps are greater will benefit more than those with smaller gaps, even if they are not brought to intake adequacy as a result of fortification. This approach measures the efficiency of the intervention, rather than the change in the prevalence of inadequate intakes, to adjust the incidence of the disease associated with each fortification formulation. It is important to note, however, that the efficiency-based DALY estimate does not "credit" additional intakes of persons with intake levels that are in excess of the EAR (as does the prevalence-based measure). Thus it measures only "effective" additional intakes, i.e., the additional nutrient intakes only of people who had inadequate intakes prior to the introduction of fortification [8].

Economic analysis of the incremental costs of each of the interventions was conducted (**fig. 1**, column 5, row 1) based on secondary data from earlier studies and

BOX 1. Bangladesh Standards and Testing Institution (BSTI) voluntary fortification regulations

Product	Regulation	Nutrient	Level
Soybean oil	BDS 1769: 2006	Vitamin A	10.0–15.0 μg/g
Edible palm oil	BDS 1770: 2006	Vitamin A	10.0–15.0 μg/g
Wheat flour (both maida and atta flours)		Calcium	53 g/kg
		Iron	55 mg/kg
		Thiamine	6 mg/kg
		Riboflavin	4 mg/kg
		Niacin	15 mg/kg
		Pyridoxine	5 mg/kg
		Vitamin B_{12}	0.01 mg/kg
		Zinc	27 mg/kg
		Vitamin A	10,000 IU/kg (3 mg/kg)
		Folic acid	2 mg/kg

combined with current fortification formulation prices obtained from the Global Alliance for Improved Nutrition (GAIN) Premix Facility. Using a modified version of the HarvestPlus DALYs methodology [38], the estimated costs of each intervention were divided by the number of DALYs it was estimated to have saved to provide an estimate of its cost-effectiveness (**fig. 1**, column 6).

To develop an estimate of the total amount of wheat flour in the Bangladesh food supply using the HIES, we identified those food items in the HIES food list that contain significant amounts of wheat. We used wheat flour milling technologists' standardized estimates of the average amount of wheat flour contained in each of those foods, and multiplied the wheat flour transformation factors by the quantities households reported apparently consuming during the recall period. We assumed that wheat flour constitutes 75% of unleavened, whole wheat bread (known as *chapati* or *parota*), 60% of white bread, 90% of pasta, 60% of biscuits, and 55% of cakes.* In light of the rapid growth in roller mill concentration and their capacity utilization rates and taking into account the quantity of the different wheat forms reported in the HIES, we estimate that 50% of bread is atta flour and 50% is maida. Combining this estimate with several assumptions about the nature and structure of the wheat flour milling industry (the first four items in **box 2**), we estimate that roughly one-quarter of the total wheat flour annually produced in Bangladesh (222,119 MT) is fortifiable.

The large-scale, modern soybean- and palm oil-producing plants—the raw input for which is almost entirely imported—are regarded as the only sources of fortifiable vegetable oil in Bangladesh. Roughly two-thirds of the mustard seed oil that is still being produced is produced by home- or artisan-based operations, and the remaining one-third is produced using small-scale technologies. It is not uncommon, however, for commercial enterprises to amass many of the small-scale operations together in a particular plant. In this study, mustard seed, with its more diverse technology and generally much smaller scale of operations, is not considered fortifiable.

The costs of interest in this study are the incremental costs of fortification, which are equal to the sum of private sector incremental fortification costs and the public sector incremental fortification costs. The total private sector incremental costs of fortification include the costs of the fortificants, premixes, blenders, dosifiers or feeders (machines to introduce the fortificant or premix), laboratory equipment, laboratory glassware and other consumables, additional production-related personnel and laboratory technicians, and monthly quality control tests conducted by an external laboratory. Recurrent costs (i.e., annual operating costs) include maintenance costs of capital items (estimated at 10% per annum), depreciation (straight-lined over 15 years), and additional administrative requirements associated with the program, together with storage and incidentals (together estimated at 5% of premix costs, which makes them vary with the level of output). Although there are new activities and responsibilities, generally few, if any, new staff are needed, and the additional costs attributable to fortification are estimated as a prorated share of the time that already-paid personnel spend on the new, fortification-specific activities.

In addition to recurrent costs, there are costs that are incurred to pay for items that have a lifespan of more than a year, so-called capital costs. Capital costs include the costs of feeders in the case of wheat flour, or mixing tanks in the case of vegetable oil, as well as laboratory equipment and the training costs of key personnel. To make capital costs more directly consistent and compatible with recurrent costs, they are annualized by simply dividing their cost by their expected life span, spreading them out over the life-span time period of the capital equipment and applying an annual discount rate to future costs. Adding these discounted, annualized capital costs to the recurrent costs provides the

BOX 2. Assumptions in the modeling of fortification

Wheat flour fortification

- All of the output of all roller mills is fortifiable
- The output of chakki mills is not fortifiable
- 100% of maida wheat flour is fortifiable
- Maida constitutes 50% of the wheat flour used to produce breads, and 100% of the wheat flour used to produce biscuits, cakes, and vermicelli/suji
- For zinc, age- and gender-specific bioavailability values are assumed: standards of IZiNCG are used for women, standards of IOM are used for children
- For iron, a baseline bioavailability of 5% is assumed
- The bioavailability of NaFeEDTA in atta flour is assumed to be 5%, that in maida is assumed to be 10%; the bioavailability of zinc in atta is half what it is in the maida

Vegetable oil fortification

- Only soybean and palm oil (76% of total vegetable oil) are fortifiable
- 85% of soybean and palm oil is fortifiable
- Regulatory requirement of 10 mg of vitamin A (measured at retail) plus an overage of 5 mg is added per kilogram
- Total vitamin A loss due to transport, storage and cooking is 47% at point of consumption

IOM, Institute of Medicine; IZiNCG, International Zinc Nutrition Consultative Group; NaFeEDTA, sodium iron ethylenediaminetetraacetate

* Quentin Johnson, Quican, Inc., personal communication. The HIES food list includes *suji*, which is a type of pasta made from semolina, the crushed endosperm of durum wheat.

total annual costs of fortification.

Although a number of industry representatives met with members of the study team, they did not allow us to visit the plant floors, meet with production managers, or collect detailed cost data. Not having undertaken primary data collection to estimate the incremental cost of vegetable oil fortification in plants of Bangladesh, we turned to secondary data sources: findings from our own primary cost data collection efforts in other countries [39–42], as well as a 2005 Bangladesh study [43].

Results

Measuring consumption of fortifiable wheat flour and fortifiable vegetable oil

Table 1 shows how consumption patterns of the two fortification vehicles vary across the country. During the 14-day recall period, 76% of Bangladeshi households purchased and consumed vegetable oil, and 65% purchased and consumed fortifiable wheat flour-containing foods. Ninety-one percent would be reached by either vegetable oil or wheat flour, and 50% would be reached by both. The coverage of vegetable oil ranged from a low of 51% in Rajshahi to a high of 95% in Barisal and Khulna. The coverage range of fortifiable wheat flour went from Barisal's low of 40% to Sylhet's high of 77%. The three divisions with the lowest coverage of vegetable oil—Rangpur, Rajshahi, and Sylhet—are the three divisions with the highest coverage of fortifiable wheat flour.

Comparing the divisional distribution of the population and the percentage of persons who would consume some of each of the four possible consumption patterns of these two vehicles (**table 1**, panel B), the percentages are found to be remarkably similar, demonstrating the highly similar dietary patterns of the people of

TABLE 1. Consumption patterns of the two fortification vehicles

Division	Population	Vegetable oil	Wheat flour–containing foods	Either vegetable oil or wheat flour foods	Both vegetable oil and wheat flour foods
Percent of persons consuming					
Barisal	8,905,211	95%	40%	99%	36%
Chittagong	26,727,815	89%	68%	99%	58%
Dhaka	44,714,603	75%	63%	90%	48%
Khulna	16,292,108	95%	59%	96%	58%
Rajshahi	17,027,785	51%	70%	81%	40%
Rangpur	16,351,424	59%	70%	84%	44%
Sylhet	8,798,802	68%	77%	90%	55%
National	138,817,749	76%	65%	91%	50%
Number of persons consuming (coverage)					
Barisal	8,905,211	8,474,440	3,559,853	8,806,546	3,227,748
Chittagong	26,727,815	23,788,189	18,167,203	26,377,701	15,577,691
Dhaka	44,714,603	33,518,683	28,261,362	40,142,455	21,637,590
Khulna	16,292,108	15,437,188	9,688,754	15,619,336	9,506,606
Rajshahi	17,027,785	8,757,520	11,932,407	13,861,067	6,828,860
Rangpur	16,351,424	9,613,927	11,444,918	13,815,913	7,242,932
Sylhet	8,798,802	6,009,541	6,802,512	7,943,717	4,868,336
National	138,817,749	105,599,489	89,857,009	126,566,735	68,889,763
Distribution of total population by division and fortifiable food combination					
Barisal	6%	6%	3%	6%	2%
Chittagong	19%	17%	13%	19%	11%
Dhaka	32%	24%	20%	29%	16%
Khulna	12%	11%	7%	11%	7%
Rajshahi	12%	6%	9%	10%	5%
Rangpur	12%	7%	8%	10%	5%
Sylhet	6%	4%	5%	6%	4%
National	100%	76%	65%	91%	50%

Bangladesh across the country's seven divisions.

Average consumption levels of fortifiable wheat flour and fortifiable vegetable oil

Table 2 presents the mean ACE quantities of purchased fortifiable wheat flour and fortifiable vegetable oil. The ACE adjusts the household per capita average by taking into account the number of household members and their age and sex. Given the level of fortification and baseline nutrient intakes, there are two consumption parameters—the food vehicle's coverage and the quantities of the food vehicle consumed—that together determine the breadth and depth of the impact of fortification. In comparing the conditional and unconditional averages, two fundamental considerations should be borne in mind: only households that are purchasing some of the food in question benefit from fortification, and the amount by which their nutrient intakes will be increased will be in direct proportion to the quantity of the fortified food they eat.

Table 2 shows the conditional and unconditional average apparent consumption levels per ACE. The unconditional averages are calculated over the entire population (including consumers and nonconsumers of the particular vehicles), while the conditional averages are calculated on the basis of only households or persons that consume some of the particular food item in question. The conditional and unconditional averages are important complementary measures for understanding the coverage and impact of fortification. The conditional average consumption level will always be greater than the unconditional average consumption level except when the entire population consumes the food item, in which case the two measures will be equal. The higher the coverage rate, the closer will be the two measures, and the lower the coverage rate, the more they will vary. The ratio of the unconditional to the conditional average consumption level for oil is 70% at both the mean and the median; that for wheat flour is 60% at the mean and 40% at the median. The higher ratios for oil reflect its relatively higher coverage rate.

The impact of fortification

Changes in prevalence

Table 3 shows the zinc and iron intake levels (adjusted for bioavailability) and the prevalence of inadequate

TABLE 2. Conditional and unconditional apparent intakes of purchased wheat flour-containing foods and vegetable oil (per adult consumption equivalent), Bangladesh HIES, 2005

Division/domain	Consumers of wheat (persons)	% consuming	Total apparent consumption grams/day	Per ACE (grams/day) Conditional Mean	Per ACE (grams/day) Unconditional Mean
Barisal	3,559,853	40	22,916,776	9.3	3.7
Chittagong	18,167,203	68	166,396,628	13.6	9.0
Dhaka	28,268,622	63	193,812,626	10.1	6.1
Khulna	9,688,754	59	50,016,735	7.3	4.2
Rajshahi	11,932,407	70	55,922,728	6.4	4.3
Rangpur	11,444,918	70	48,467,079	6.0	4.0
Sylhet	6,802,512	77	71,012,668	15.0	11.1
Rural	67,276,533	64	390,386,304	8.4	5.2
Urban	22,587,735	66	218,158,935	13.3	8.4
National	89,864,269	65	608,545,239	9.6	6.0
Division/domain	**Consumers of oil (persons)**	**% consuming**	**608,545,239**	**Per ACE (g/d) Conditional Mean**	**Per ACE (g/d) Unconditional Mean**
Barisal	8,474,440	95	100,439,098	17.1	16.2
Chittagong	23,788,189	89	392,869,910	23.9	21.2
Dhaka	33,518,683	75	707,803,830	30.6	22.6
Khulna	15,437,188	95	252,349,647	22.9	21.6
Rajshahi	8,757,520	51	100,722,485	15.7	7.8
Rangpur	9,613,927	59	98,410,479	14.3	8.2
Sylhet	6,009,541	68	103,652,601	25.5	17.3
Rural	72,924,650	70	1,015,560,366	20.0	13.5
Urban	32,674,839	95	740,687,683	32.1	30.4
National	105,599,489	76	1,756,248,049	23.9	17.8

ACE: Adult consumption equivalent

zinc intakes at baseline and with wheat flour fortification (i.e., at endline), assuming the iron compound used is sodium iron ethylenediaminetetraacetate (NaFeEDTA). The last column on the right in section A shows the percentage point change in the prevalence of inadequate zinc intakes due to wheat flour fortification. Nationwide, zinc fortification of wheat flour results in a meager 0.8 percentage point reduction in the prevalence of inadequate zinc intake. The division-specific impacts vary by a factor of almost three, but none ever achieves more than a 1.4 percentage point reduction. Divisional percentage point reductions vary from 0.5 in Rangpur and Barisal to 1.1 in Chittagong and 1.4 in Sylhet. Without zinc fortification of wheat flour, the prevalence of inadequate zinc intake in Bangladesh is 72%; with it, the prevalence is 71%. Recalling that the level of wheat consumption peaked in the late 1990s, it is evident that wheat fortification has at best a minor role to play in helping to reducing zinc deficiency in Bangladesh. Unless the wheat consumption trend reverses and average levels increase fairly substantially, the only source of dynamism in modifying this situation will be that provided by the growth in the proportion of all wheat flour that consists of fortifiable wheat flour due to the expected continued growth in concentration of milling by the roller mills as, over time, they continue to displace chakkis.

The impacts of iron are very similar to those of zinc: reaching a large share of Bangladeshis, but with only a relatively small additional intake. The baseline prevalence of inadequate iron intake, 81%, is reduced by only 1.5 percentage points by wheat flour fortification, to 79%.

Table 4 presents the same measures for vitamin A and includes three sets of endline measures, one for wheat flour fortification, a second for oil fortification, and a third for a portfolio including both vehicles. Here too, wheat flour fortification results in a 2 percentage point reduction in the prevalence of inadequate vitamin A intake from 83% to 81%. The impact of vegetable oil fortification is much greater, reducing the prevalence of inadequate vitamin A intake by 19 percentage points to 64%. Fortifying both vehicles results in a 21 percentage point reduction to 62%.

DALYs saved by fortification

Section A of **table 5** shows the DALY burden of zinc, vitamin A, and iron deficiencies in Bangladesh at baseline. Vitamin A deficiency is responsible for by far the largest number of micronutrient deficiency-attributable DALYs in Bangladesh at baseline, 74% of the total attributable to the three micronutrients being considered here. The total number of vitamin A deficiency-attributable DALYs is roughly four times the number attributable to zinc deficiency, and more than seven times the number attributable to iron deficiency.

TABLE 3. Zinc and iron intake levels and prevalence of inadequate intake at baseline and endline with wheat flour fortification

		Baseline		Wheat flour fortification		
					Endline prevalence of inadequate intake	
Division	Population	Mean intake (mg)	Prevalence of inadequate intake (%)	Mean intake (mg)	Prevalence	PPT change
A. Zinc						
Barisal	8,905,211	1.84	81	1.85	81%	0.5%
Chittagong	26,727,815	2.11	70	2.14	69%	1.1%
Dhaka	44,714,603	2.28	66	2.30	65%	0.8%
Khulna	16,292,108	2.00	79	2.02	79%	0.6%
Rajshahi	17,027,785	2.31	72	2.32	71%	0.6%
Rangpur	16,351,424	1.92	79	1.94	78%	0.5%
Sylhet	8,798,802	2.03	74	2.07	72%	1.4%
National	138,817,749	2.13	72	2.15	71%	0.8%
B. Iron						
Barisal	8,905,211	0.72	83	0.73	82%	1.0%
Chittagong	26,727,815	0.77	79	0.80	77%	2.2%
Dhaka	44,714,603	0.81	76	0.83	74%	1.6%
Khulna	16,292,108	0.74	80	0.75	80%	0.9%
Rajshahi	17,027,785	0.67	85	0.69	84%	0.9%
Rangpur	16,351,424	0.61	89	0.62	88%	1.0%
Sylhet	8,798,802	0.71	84	0.75	81%	3.0%
National	138,817,749	0.74	81	0.76	79%	1.5%

TABLE 4. Vitamin A intake levels and prevalence of inadequate intake at baseline and at endlines with fortification interventions

		Baseline		Wheat flour fortification			Vegetable oil fortification			Wheat flour and vegetable oil fortification		
					Endline prevalence of inadequate intake			Endline prevalence of inadequate intake			Endline prevalence of inadequate intake	
Division	Population	Baseline intake (µg)	Prevalence of inadequate intake (%)	Endline intake (µg)	%	PPT change	Endline intake (µg)	%	PPT change	Endline intake (µg)	%	PPT change
Barisal	8,905,211	321	84	330	82	1%	436	65	18%	445	64	20%
Chittagong	26,727,815	306	84	327	82	3%	456	61	23%	477	58	26%
Dhaka	44,714,603	303	84	317	82	2%	464	57	27%	478	56	29%
Khulna	16,292,108	373	72	384	71	1%	531	55	17%	542	54	18%
Rajshahi	17,027,785	295	82	306	82	1%	355	75	8%	366	74	9%
Rangpur	16,351,424	271	84	281	84	1%	332	78	7%	342	76	8%
Sylhet	8,798,802	248	94	274	91	2%	368	75	18%	394	71	22%
National	138,817,749	305	83	319	81	2%	434	64	19%	448	62	21%

PPT change: percentage point change — baseline minus endline

Sections B, C, and D of **table 5** show the endline estimates with wheat flour fortification formulation 1 and vegetable oil fortification. Of the total reduction of 137,461 DALYs that wheat flour fortification would produce, 77% would be due to reducing inadequate intake of vitamin A, 12% to reducing inadequate iron intake, and 11% to reducing inadequate zinc intake. Wheat flour fortification would result in annual savings of 105,255 DALYs, a 12.5% reduction in the total vitamin A deficiency-attributable DALYs. The impact on inadequate iron intake would be the next largest, with the total number of iron deficiency-attributable DALYs being reduced by 16,495 (14%). The smallest impact of wheat flour fortification would be on inadequate zinc intake: the number of zinc deficiency-attributable DALYs would be reduced by 15,708 (8%).

Wheat flour fortification using formulation 2 would save 12% of the 1,178,898 DALYs attributable to deficiencies of all three of these micronutrients. Although the reduction in the number of DALYs attributable to zinc deficiency is not enormous (8%), it is more than seven times greater than the 1.1% reduction in the prevalence of inadequate zinc intake. The comparable relative measures for vitamin A are 12% and 25.3%, respectively, and those for iron are 14% and 1.9%, respectively. Given the very large variations by micronutrient in these measures, it is evident that how the relative impacts of wheat flour fortification are measured will have important implications for how we characterize the three micronutrients' relative impacts and thus in how we rank their relative performances and prioritize them. It is important, therefore, to carefully examine these alternative measures and assess their alternative policy implications.

If we measure changes in prevalence, vitamin A fortification produces the largest absolute and relative impacts. If we use DALYs saved, whereas vitamin A fortification produces by far the largest absolute impact, iron fortification produces the largest relative impact. Of the three micronutrients, the relative performance measure of iron fortification is the most affected by the selection of impact measure: the ratio of its percentage reduction in DALYs to its percentage reduction in prevalence is the greatest. Regardless of which measure is used, zinc is the poorest performer of the three micronutrients: zinc fortification produces the smallest reduction in DALYs and the smallest percentage reduction in prevalence, as well as the smallest percentage point reduction in prevalence.

The change in DALYs produced by wheat flour fortification is far greater than the change in the prevalence of inadequate intake, underscoring the significance of which metric is used in assessing these interventions.

Fortification of vegetable oil with vitamin A would reduce the number of DALYs attributable to vitamin A deficiency by 406,877. It would account for 47% of the reduction in DALYs attributable to vitamin A

TABLE 5. The health burden of micronutrient deficiencies in Bangladesh: Years of life lost, years living with disability and disability-adjusted life years due to iron deficiency anemia (IDA), vitamin A deficiency and zinc deficiency

Deficiency	Number of deaths	Discounted YLLs	Discounted YLDs	DALYs
A. Baseline				
IDA	2,400	63,349	58,182	121,531
Vitamin A	26,999	785,027	87,366	872,393
Zinc	5,715	166,573	18,401	184,974
Total (all 3 deficiencies)	35,114	1,014,949	163,949	1,178,898
IDA	7%	6%	35%	10%
Vitamin A	77%	77%	53%	74%
Zinc	16%	16%	11%	16%
Totals	100%	100%	100%	100%
B. Total DALYs saved[a]				
IDA-wheat	229	6,039	10,459	16,498
Vitamin A-oil	12,477	362,768	44,109	406,877
Vitamin A-wheat	3,213	93,418	11,837	105,255
Vitamin A-oil and wheat	13,761	400,121	47,571	447,692
Zinc-wheat	328	9,561	6,146	15,708
C. Percent of DALYs saved				
IDA-wheat	10%	10%	18%	14%
Vitamin A-oil	46%	46%	50%	47%
Vitamin A-wheat	12%	12%	14%	12%
Vitamin A-oil and wheat	51%	51%	54%	51%
Zinc-wheat	6%	6%	33%	8%
D. Percent of total DALYs from all 3 micronutrient deficiencies saved				
Wheat	11%	11%	17%	12%
Oil	36%	36%	27%	35%
Oil and wheat	41%	41%	39%	41%

a. Assumes fortification with wheat flour formulation 1.

deficiency and 35% of the total reduction in DALYs attributable to deficiencies of all three micronutrients. It also would result in a reduction in the prevalence of inadequate vitamin A intake of 19 percentage points. Fortification of vegetable oil with vitamin A would have about four times the impact of fortification of wheat flour with vitamin A and about three times the impact of fortification of wheat flour, which includes DALYs saved by iron and zinc, in addition to vitamin A. Combining vegetable oil and wheat flour fortification would produce an incremental savings of 40,815 DALYs (447,692 minus 406,877) and would result in a total reduction of DALYs due to vitamin A deficiency of 51%. Adding fortification of wheat flour to fortification of vegetable oil would also result in a modest increase (8%) in the number of additional DALYs saved—an additional 22,206 more than what oil fortification alone would save—because it also would save DALYS by reducing zinc and iron deficiencies. The total number of DALYs that could be averted by fortifying both wheat flour and vegetable oil would be 479,898, 41% of the total DALYs lost due to deficiencies of zinc, vitamin A, and iron in the absence of any fortification program. Of the total DALYs that could be averted by fortifying both vehicles, those due to reducing zinc deficiency (15,708) would constitute a minor share of the total, only 2%.

The relatively small potential impact of fortification of wheat flour with zinc and the relatively minor contribution of wheat flour fortification to reducing the micronutrient disease burden of Bangladesh reflects a number of factors:

» The relatively much greater importance of the burden of vitamin A deficiency prior to fortification;
» The greater coverage of vegetable oil vis-à-vis wheat flour;
» The relatively greater average daily dose as a percentage of EAR that can be delivered for vitamin A compared with zinc (which is due to a combination of the relative fortification levels, together with the average quantities of the food vehicles consumed); and

» The relatively higher EAR gap at baseline of vitamin A, compared with that of iron or zinc.

Costs and cost-effectiveness of fortification

Although the absolute level of costs of fortification varied substantially across the five costing studies we reviewed [39–43], the proportion of total costs accounted for by fortificants was similar, varying from 83% to 97% for vegetable oil and from 85% to 99% for wheat flour. The Bangladesh study [43] found that the fortificant accounted for 97% of the total private sector incremental cost per metric ton of vegetable oil and 89% of the cost per metric ton of wheat flour (**table 6**). This was at the high end of the range documented in other studies and did not include the costs of quality assurance. Assuming the cost structure of fortification had remained the same, we reduced the Bangladesh-specific study cost share of the fortificant to 85% for wheat flour and 92% for vegetable oil, obtained Bangladesh-specific fortificant cost estimates, and used the fortificant's modified percentage share of total costs to back-calculate the total incremental private-sector costs of fortifying a metric ton of each food vehicle. We also estimated the incremental public-sector costs of monitoring the food fortification program (not presented).

Costs of private-sector fortification of wheat flour

Table 7 shows the costs of wheat flour premix using four different fortification formulations. Estimates of the cost of the retinyl palmitate (the vegetable oil fortificant) and of the wheat flour premix, their required incorporation rates, as well as customs, insurance, and freight costs, were prepared by the GAIN Premix Facility. Formulations 1 and 2 are the most policy-relevant for Bangladesh; they are both based on the official Bangladesh fortification regulations (**box 2**). Although the official regulations call for the addition of iron, they do not specify the iron compound. Different iron compounds have different levels of efficacy and different costs [44]. We present analyses of the costs of NaFeEDTA and ferrous fumarate to provide policy-relevant evidence to inform the cost–impact tradeoff decision.

Formulations 3 and 4 are provided to demonstrate the price sensitivities of alternative formulations. The particular formulations adopted include only the three nutrients for which there are adequately rigorous measures of the effectiveness of fortification such that there are algorithms for estimating the number of DALYs saved by consuming the fortified wheat flour; only the costs and impact and cost-effectiveness of zinc, vitamin A, and iron are calculated.

The cost of wheat flour premix containing NaFeEDTA (formulation 1) is US$9.26/kg. This is 89% of the cost of formulation 2, which uses ferrous fumarate and costs US$10.39/kg. Although the cost per kilogram of the premix with NaFeEDTA is less, because its rate of incorporation into the wheat flour is 50% greater than that of the ferrous fumarate-based premix, the premix cost of fortifying 1 MT of wheat flour with NaFeEDTA is actually 34% greater, US$8.33 compared with US$6.23. The cost of formulation 3 premix is US$10.90/kg and that of formulation 4 is US$8.95/kg. Relative to the cost of formulation 1, the costs of fortifying 1 MT of wheat flour using formulations 2, 3, and 4 are 75%, 64%, and 39%, respectively.

TABLE 6. The structure of vegetable oil and wheat flour fortification costs in Bangladesh

Type of cost	Item	Vegetable oil (%)	Wheat flour (%)
Investment costs		5.17	29.54
	Annualized (15-year amortization)	0.30	1.97
Variable costs			
	Operating costs of equipment		
	Maintenance and repair (at 10%)	0.42	2.95
	Electrical power	0.12	0.19
	Other operating costs		
	Labor	0.20	0.91
	Internal quality control testing	1.80	4.13
	External quality control testing	0.48	1.10
	Vitamin A	96.63	88.74
	Total variable costs	99.66	98.03
Annualized investment costs with 15-year amortization		0.34	1.97
Annual variable costs		99.66	98.03
Total annualized costs		100.00	100.00

Source: Adapted from Dary and Rassas [43].

To estimate the total costs of the premix, it is necessary to factor in the costs of customs, insurance, and freight, which are estimated at 17% of the costs of the fortificants. The total cost of each of the fortificants in each of the four formulations, the total incremental cost of fortifying 1 MT of wheat flour (assuming the cost of premix is 85% of the total costs), and the total annual cost of fortifying all fortifiable wheat flour in Bangladesh are shown in **table 8**. Fortifying all of the 222,119 MT of what has been identified as fortifiable wheat flour in Bangladesh at BSTI-established levels will cost about US$2.55 million a year if the iron compound used is NeFeEDTA. It will cost 25% less, about US$1.9 million, if ferrous fumarate is used.

Formulation 1 with NaFeEDTA has a premix cost that is 33.7% higher than that of formulation 2 with ferrous fumarate. Although the use of NaFeEDTA results in twice as many DALYs saved as the use of ferrous fumarate, the small absolute number of all iron-attributable DALYs saved with NaFeEDTA (16,498), and the fact that iron-attributable DALYs constitute only 12% of all of the DALYs saved by wheat flour fortification,

TABLE 7. Wheat flour premixes: Costs by formulation, types of iron compound, quantities

	Formulation 1: NaFeEDTA, Zn, VA + 7 other micronutrients	Formulation 2: FF, Zn, VA + 7 other micronutrients	Formulation 3: Zn+NaFeEDTA+VA	Formulation 4: Zn+FF+VA
A. Quantity and cost measures				
Incorporation rate	900 g/MT	600 g/MT	600 g/MT	300 g/MT
Cost of premix/kg	US$9.26	US$10.39	US$8.95	US$10.90
Cost of fortification/MT flour	US$8.33	US$6.23	US$5.37	US$3.27
Customs, insurance and freight	US$1.42	US$1.06	US$0.91	US$0.56
Other costs	US$1.72	US$1.29	US$1.11	US$0.68
Total cost/MT	US$11.47	US$8.58	US$7.39	US$4.50
Quantity of nutrient form in premix (g/kg)	890.8	893.6	876.0	867.0
Quantity of carrier in premix (g/kg)	109.2	106.4	124.0	133.0
B. Quantities of individual nutrients				
Nutrient–compound	Overage	Quantities of nutrients		
Fe–NaFeEDTA or ferrous fumarate	0%	55 mg/kg		
Zn–Zinc oxide	0%	27 mg/kg		
Vitamin A (dry) 250,000 IU/g	30%	4 IU/g		
Ca–Di-calcium phosphate $2H_2O$	0%	53 mg/kg		
Vitamin B_1–Thiamine mononitrate	20%	6 mg/kg		
Vitamin B_2–Riboflavin	0%	4 mg/kg		
Vitamin B_3–Niacinamide	0%	15 mg/kg		
Vitamin B_6–Pyridoxine hydrochloride	0%	5 mg/kg		
Vitamin B_9–Folic acid	20%	2 mg/kg		
Vitamin B_{12}–0.1% WS	20%	0.010 mg/kg		

FF, ferrous fumarate, MT, metric ton; NaFeEDTA, sodium iron ethylenediaminetetraacetate; VA, vitamin A; WS, water soluble; Zn, zinc

TABLE 8. Private sector cost of wheat flour fortification in Bangladesh

Cost item	Formulation 1: Zn+NaFeEDTA+VA+7	Formulation 2: Zn+FF+VA+7	Formulation 3: Zn+NaFeEDTA+VA	Formulation 4: Zn+FF+VA
Total annual cost	$2,548,044	$1,905,369	$1,641,825	$999,771
Percentage	100%	75%	64%	39%
DALYs saved	137,461	129,212	137,461	129,212
Total annual cost	$2,548,044	$1,905,369	$1,641,825	$999,771
Cost per DALY saved	$18.54	$14.75	$11.94	$7.74
Percentage (cost/DALY saved)	100%	80%	64%	42%

DALY, disability-adjusted life year; FF, ferrous fumarate; MT, metric ton; NaFeEDTA, sodium iron ethylenediaminetetraacetate; VA, vitamin A; 7 indicates the seven other micronutrients included in the fortificant formulation (identified in table 7) using NaFeEDTA drives the average cost per DALY saved up from US$14.75, the level obtained with the ferrous fumarate-based formulation 2, to US$18.54, an increase of 26%. The incremental additional DALYs saved in going from formulation 2 to formulation 1 are "purchased" at a cost of US$642,675. The incremental cost per DALY saved of these additional 8,249 DALYs is US$77.91, five times more than the average cost with the use of formulation 2. The additional 8,249 DALYs represent 6% of the total DALYs saved as a result of wheat flour fortification, but they require an additional 25% increase in costs over those with the use of formulation 2.

Costs of private-sector fortification of vegetable oil

We estimate that 544,891 MT of vegetable oil is fortifiable. To fortify oil at 15 ppm with vitamin A palmitate 1.7 mIU/g requires an incorporation rate of 29.4 g per metric ton of oil. The price of vitamin A palmitate 1.7 mIU is US$62.50/kg. Adding estimates of costs for customs, insurance, and transportation at 17%, the total cost of the fortificant comes to US$73.12/kg, which (given the incorporation rate) comes to US$2.141 per metric ton of oil. Assuming that the cost of premix is 92% of the total private sector cost per metric ton of oil, it is estimated that the private sector costs of fortifying one metric ton of oil in Bangladesh is US$2.327 and that the total cost of fortifying the 544,891 MT of fortifiable vegetable oil is US$1.27 million.

The cost per DALY saved from the use of vitamin A–fortified vegetable oil is US$3.12. Comparing the cost and impacts of vegetable oil fortification with those of wheat flour fortification using formulation 2 reveals that the costs of wheat flour fortification are 50% greater than those of oil fortification, the public health impact of wheat flour fortification (total DALYs saved) is about 32% of that of oil fortification, and the cost per DALY saved is 4.7 times higher than that of oil fortification. Fortification of wheat flour with formulation 1 compares even more poorly with fortification of oil. The costs of fortification of wheat flour with formulation 1 are twice the costs of fortification of oil, the number of DALYs saved is 34% of those saved by fortification of vegetable oil, and the costs per DALY saved are 6 times larger. By these measures, vegetable oil fortification is the more attractive option: more attractive than fortification of wheat flour with formulation 2 and relatively even more attractive than fortification of wheat flour with formulation 1.

The incremental costs of fortifying both vegetable oil and wheat flour

Section A of **table 9** presents the total DALYs saved, total costs, and total cost per DALY saved of a fortification program that consists of two fortified foods, wheat flour and vegetable oil, combining each of the different wheat flour fortification formulations with vegetable oil. The cost per DALY saved of the two-food fortification interventions is roughly twice that of fortification of vegetable oil alone and about half that of fortification of wheat flour alone (regardless of which wheat flour fortification formulation is the comparator).

The World Health Organization (WHO) and the World Bank have suggested two different criteria for assessing the cost-effectiveness of health programs. WHO's CHOICE (Choosing Interventions that are Cost Effective) Working Group has suggested that a health intervention should be considered "cost-effective" if its cost per DALY saved is less than one to three times the per capita annual income, and it should be regarded as "very cost-effective" if its cost per DALY saved is less than the per capita annual income [11]. Bangladesh's

TABLE 9. DALYs saved, total costs and cost per DALY saved by alternative fortification programs

	Vegetable oil with alternative wheat flour fortification formulations			
	Formulation 1 Zn+NaFeEDTA+VA+7	Formulation 2 Zn+FF+VA+7	Formulation 3 Zn+NaFeEDTA+VA	Formulation 4 Zn+FF+VA
A. Program including both vegetable oil and wheat flour fortification				
DALYs saved	479,898	471,599	479,898	471,599
Total annual cost	$3,816,160	$3,173,484	$2,909,941	$2,267,886
Cost per DALY saved	$7.95	$6.73	$6.06	$4.81
Percentage	100%	85%	76%	60%
B. Incremental measures of adding wheat flour to a vegetable oil fortification program				
Incremental DALYs saved	73,021	64,722	73,021	64,722
Incremental annual cost	$2,548,044	$1,905,369	$1,641,825	$999,771
Incremental cost per DALY saved	$34.89	$29.44	$22.48	$15.45
Percentage	100%	84%	64%	44%

DALY: disability-adjusted life year; FF: ferrous fumarate, MT, metric ton; NaFeEDTA: sodium iron ethylenediaminetetraacetate; VA: Vitamin A; Zn, zinc; 7: Indicates the 7 other micronutrients included in the fortificant formulation (identified in Table 7).

2012 per capita income was equal to US$640. Thus, by the WHO criterion, all of these intervention formulations are "very cost-effective."

In its seminal 1993 *World Development Report: Investing in Health*, the World Bank stated that a public health intervention with a cost of less than US$150 per DALY saved (in 1990 dollars) was "very cost-effective." Adjusting this value for the change in the purchasing power of the dollar provides us with an alternative threshold of US$268 per DALY saved [45]. By this measure too, all of these formulations are "very cost-effective."

The incremental cost and impacts of adding wheat flour to vegetable oil fortification

Given that Bangladesh already has vegetable oil fortification, a more immediate policy-relevant concern might be: What would be the impact of introducing wheat flour fortification and adding it to the current vegetable oil program? Would it be worth it? The incremental cost per DALY saved is US$34.89 for fortification of wheat flour with formulation 1 and US$29.44 for fortification with formulation 2: roughly four times the two-food vehicle cost per DALY saved and about twice the cost per DALY saved by wheat flour fortification alone.

Vitamin A is one of the more expensive micronutrients. It adds significantly to the cost of the wheat flour fortification formulation. What would be the impact on costs, DALYs saved, and cost-effectiveness if vitamin A were dropped from the wheat flour formulation? Excluding vitamin A would result in the fortification cost per metric ton of wheat flour falling by 22% using fortification formulation 1, and 30% using fortification formulation 2. The change in formulation would cause the cost-effectiveness of wheat flour fortification to fall even faster, however, owing to the loss of impact on vitamin A deficiency (which, as already noted, constitutes by far the greatest health burden among the three micronutrient deficiencies). As a result, the incremental cost per DALY saved of formulation 1 would increase by 76% from US$34.89 to US$61.33, and that of formulation 2 would increase from US$29.44 to US$55.76. In sum, although the formulations with vitamin A are quite a bit more expensive, they are also proportionately more effective and more cost-effective than the identical formulations without vitamin A.

Discussion

The study has several limitations. In addition to the shortcomings of DALYs discussed earlier, as also noted earlier, some of the food items in the HIES that contain potentially fortifiable wheat flour were not included in these simulations. Most of these are not likely to have a significant additional impact on these estimates due to low household coverage and consumption estimates, although there are three—*puri, rasogolla,* and *jilapi*—that are consumed by large portions of the population (28.5%, 9.5%, and 10.7% of households, respectively). We were unable, however, to find consistent information on the amount of wheat flour contained in these products or the extent to which the flour used is likely to be fortifiable. As a result, we may have considerably underestimated the level of consumption of fortifiable wheat flour, and thus the potential impact of wheat flour fortification.

A third limitation of the study relates to our assumption that all of the fortified vegetable oil is consumed. It is likely that a percentage of the vegetable oil that is consumed is used for cooking. When vegetable oil is used for cooking, or more specifically frying, a greater percentage of it will go to waste. Although vitamin A remains stable when the oil is cooked or boiled, it rapidly degrades when the oil is used for frying [46]. As much as 35% of vitamin A may be lost by frying, and even greater losses may result if the oil is reused for frying. In this analysis, losses due to cooking were assumed to be 20%; however, in cases where the oil is used for frying, the losses may be higher. The impact of vegetable oil fortification in this study, therefore, is likely to be overestimated.

Finally, it is worth underscoring the finding that although the cost-effectiveness of fortifying wheat flour is substantially less than that of fortifying vegetable oil, as judged by WHO and World Bank criteria, fortifying wheat flour is, nevertheless, a highly cost-effective intervention. There are very few other health or nutrition interventions that Bangladesh could invest in that would provide impacts as cost-effectively as wheat flour fortification [47, 48]. Thus, although vegetable oil is the better vehicle—with greater coverage, lower costs, and higher cost-effectiveness—Bangladesh would be well advised to introduce wheat flour fortification as well.

Authors' contributions

Jack Fiedler conceptualized the study, developed the costing methodology and the industry analyses, participated in data analysis, and prepared the manuscript. Keith Lividini developed the modeling tool to operationalize the study design, finalized the nutrient analytic file, led the data analysis, and reviewed and edited the manuscript. Odilia Bermudez prepared the initial nutrient intake analytic file and reviewed and edited the manuscript. Christophe Guyondet prepared estimates of the contents of the fortification formulations and of incorporation rates and costs and reviewed the manuscript.

Acknowledgments

The authors gratefully acknowledge the support of the Bill & Melinda Gates Foundation's Nutrition and Economic Research Support to HarvestPlus for Grand Challenge 9 Projects Grant OPP52013.

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From diets to foods: Using linear programming to formulate a nutritious, minimum-cost porridge mix for children aged 1 to 2 years

Irene Stuart Torrié De Carvalho, Yvonne Granfeldt, Petr Dejmek, and Andreas Håkansson

Abstract

Background. *Linear programming has been used extensively as a tool for nutritional recommendations. Extending the methodology to food formulation presents new challenges, since not all combinations of nutritious ingredients will produce an acceptable food. Furthermore, it would help in implementation and in ensuring the feasibility of the suggested recommendations.*

Objective. *To extend the previously used linear programming methodology from diet optimization to food formulation using consistency constraints. In addition, to exemplify usability using the case of a porridge mix formulation for emergency situations in rural Mozambique.*

Methods. *The linear programming method was extended with a consistency constraint based on previously published empirical studies on swelling of starch in soft porridges. The new method was exemplified using the formulation of a nutritious, minimum-cost porridge mix for children aged 1 to 2 years for use as a complete relief food, based primarily on local ingredients, in rural Mozambique.*

Results. *A nutritious porridge fulfilling the consistency constraints was found; however, the minimum cost was unfeasible with local ingredients only. This illustrates the challenges in formulating nutritious yet economically feasible foods from local ingredients. The high cost was caused by the high cost of mineral-rich foods. A nutritious, low-cost porridge that fulfills the consistency constraints was obtained by including supplements of zinc and calcium salts as ingredients.*

Conclusions. *The optimizations were successful in fulfilling all constraints and provided a feasible porridge, showing that the extended constrained linear programming methodology provides a systematic tool for designing nutritious foods.*

Key words: Child malnourishment, consistency, emergency nutrition rations, linear programming, micronutrient inadequacy, Mozambique

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Introduction

Among all the challenges in the field of nutrition, child malnutrition is of special relevance and importance. Child malnutrition and high mortality are common in developing countries [1–4]; among other factors, inappropriate foods and feeding practices play a major role in the etiology of malnutrition [5–7]. The lack of minerals and vitamins leads to negative health consequences [8]. Deficits in micronutrients, such as calcium, iron, and zinc, are common in home-based complementary diets fed to young children in developing countries [9, 10]. The severe negative effects of zinc deficiency on human health in developing countries have only recently been recognized by the United Nations [11]. During childhood, zinc deficiency causes stunting and impaired cognitive function, increases the incidence and severity of acute and persistent diarrhea and acute lower respiratory infections, and possibly increases the incidence of malaria [12].

Linear programming has emerged as an important tool for aiding in developing food-based recommendations [13–18]. The method has been used extensively to develop population- and individual-specific recommendations [19, 20], to investigate the economic effect of supplementation and food aid [16, 21], to find limiting micronutrients [22], and to investigate to what extent budget constraints influence the possibility of choosing healthy diets [23, 24].

Many of the above-mentioned studies include cultural constraints to make sure that the recommendations are reasonably palatable, for example, by requiring that a single group of foods does not constitute a larger portion of the total intake than is customary in the region [16], that foods are consumed in specific relative amounts [13], and that the deviation from the present diet is small [17, 23, 24]. Despite these precautions, it is not trivial to translate the obtained recommendations; it is not always easy for the intended target group to translate these more general recommendations to food preparation. Cultural and palatability constraints may ensure that the ingredients are consumed in reasonable proportions, but not that the optimizations will produce amounts of ingredients that could be used to formulate a food with an acceptable structure.

Extending the linear programming methodology from dietary recommendations to formulating menus or foods could thus help in implementation and testing the feasibility of the recommendations. However, designing foods creates additional challenges compared with forming dietary recommendations. Foods need to fulfill a number of new sensory and consistency constraints. Food consistency is arguably the most important technological property of a food if it is to be used for children at risk for malnutrition or starvation.

In many parts of Africa, children are fed with mashed adult food or starchy staples that, when cooked with water, absorb a large amount of water and swell up. The foods become viscous and bulky, with low energy and nutrient density [25]. Such inadequacies are further aggravated if infants receive very few feedings per day [9]. Cereals or starchy roots and tubers are also used as a basis for complementary foods, usually prepared as thin gruels. A wide range of supplementary foods has been developed by research groups [25–27] and the food industry [28]. However, the linear programming methodology has not yet been fully harnessed for the design of complementary or supplementary foods. A first step was taken by Dibari et al. [29] in using linear programming to design a therapeutic food for children. Consistency was ensured by requiring sufficient fat content to give a paste-like texture. However, consistency constraints are more challenging to formulate than traditional nutritional constraints, since there is no sufficiently accurate yet simple method to estimate the consistency or even the rheological properties of a food from its composition, and thus there are no generally agreed-upon limits. The extension of the linear programming methodology to food requires a firm understanding of how swelling of the commonly used starchy ingredients influences consistency. In previous studies, we investigated the relationship between consistency and concentration of starch flours used both individually [30] and in binary mixtures [31]. These data are used in the present study as the empirical basis for formulating consistency constraints to ensure that the chosen ingredients not only are nutritious but also constitute an acceptable food.

The specific aim of this study was to extend the linear programming methodology from general diet recommendations to food formulation by requiring the chosen ingredients to make up a food with acceptable consistency for the intended consumer group. The long-term objective of the research project is to develop a method for designing nutritious, palatable, and cost-effective foods to be used, for example, for emergency relief and complementation. The methodology presented in this study is thus exemplified using the formulation of a nutritious, minimum-cost porridge mix for use among children aged 1 to 2 years in rural Mozambique. In addition to the aforementioned problems of malnutrition in this group, the strict requirements for both consistency and the limiting total mass of food make these conditions a challenging test for the proposed extension. The mix should preferably be based on locally available ingredients to keep transportation costs low and to ensure that the obtained formulation is culturally acceptable. The formulation can be applied as a centrally prepared emergency food that can be distributed as part of aid programs or food relief.

Method of development

Linear programming and consistency constraints

Linear programming as a systematic method to find the lowest-cost mix to fulfill a set of nutritional requirements has been comprehensively described elsewhere [13, 16, 17]. However, additional constraints need to be added to ensure an acceptable consistency when extending the method from diets to foods. The effects of concentration on swelling and the consistency of porridges from starchy flours found locally in Mozambique have been studied in a previous paper [30]. Two commercial porridges for children (oat and oat or wheat meal) were used as references. Each of the locally available flours in **table 1** was mixed with different amounts of hot water until the same consistency as that in the reference samples was reached. **Table 1** shows the highest concentration of each flour that could be added without exceeding the consistency of the reference samples.

Each row in **table 1** refers to porridges prepared using a single flour. A second study was conducted to investigate any synergetic effect on swelling of binary mixtures. The results show that an equal blend of two porridges, each having a flour concentration according to **table 1**, results in a mix with a consistency at or below that of the commercial reference [31]. Thus, ensuring that none of the flours are added to the product at a flour-to-water ratio above that given in **table 1** will ensure that the consistency of the mix is not too

TABLE 1. Maximum concentration of flours to give acceptable porridge consistency, used as equality constraints in the optimization

Flour	Maximum concentration (g flour/100 g porridge)
Cowpea	12
Orange-fleshed sweet potato	14
Dehulled soybean	24
Dehulled maize	10
Dehulled sorghum	11
Germinated maize	36
Roasted cassava (*garri*)[a]	15

Source: Data adapted from De Carvalho et al. [30].
a. Data on swelling of roasted cassava flour were not available. Data show actual concentrations in roasted cassava porridge [32].

thick. Supplementary or emergency relief foods are designed to achieve a high energy and nutrient density, so there is no reason to include any of the flours below the flour-to-water ratios in **table 1**. Thus, the consistency constraint was implemented by forcing each unit weight of starchy flour to be accompanied by as much water as needed to give the composition indicated in **table 1**. In other words, the linear programming algorithm will use individual porridges prepared according to **table 1**, rather than the individual flours, as decision variables.

A second consistency constraint was included by limiting the dry matter content to 25% in order to take into account the influence of the remaining ingredients on consistency. The dry matter content of traditional baby-food porridges is often low, approximately 20% [32]. The higher upper limit for dry matter content used here is motivated by the finding that children in rural Mozambique often eat solid foods such as rice, nuts, and thick maize porridge at an early age. Furthermore, all introduced constraints will add to the cost of the final product and must be introduced with care, since poverty is widespread in the region. More than 50% of all families in Mozambique live under the poverty income level of US$1.25/day [33], and families have on average five children [34].

Finally, the total mass of reconstituted porridge was limited to ensure that the total porridge volume would not exceed the daily gastric capacity. Gastric capacity varies with weight and age of the child. Here a total maximum intake of 1,000 g/day was assumed, which is in approximately the same range as the mass obtained by adding the components of the US Department of Agriculture (USDA) recommendations for 2-year-old children [35]. The limit is higher than the 600 g/day that has been suggested for infants [36].

Shadow price analysis

Linear programming is a technique brought into nutrition and food science from economics, management, and operations research. Economists are often interested in how total cost depends on different constraints in order to find, for example, limiting production factors. The cost of each constraint is described as the “shadow price” in economics. The shadow price equals the Lagrangian multiplier of the corresponding constraint in the mathematical optimization problem. It is obtained directly from standard linear programming algorithms. Shadow prices have not yet—to the best of our knowledge—been used in nutrition linear programming, but they can be used to measure how costly each nutrient requirement is to fulfill. More formally, each constraint will have a corresponding shadow price describing how much the objective function (total cost) would decrease if the constraint was relaxed one unit [37].

The Mozambican porridge mix example

A list of feasible, locally available ingredients to include in the porridge mix was obtained from a survey of local food markets and a preliminary survey of the eating habits of children under 5 years old in the Maputo Province of Bobole, located in rural Mozambique (24-hour recalls of three consecutive days, $n = 47$). The final list of food ingredients includes the flours in **table 1**, nuts, leaves, fruits, beans, vegetable oil, and vegetables. Meat and seafood ingredients were excluded because they are expensive and are consumed only as luxury foods in the region and are therefore not relevant as ingredients in low-cost relief food. This assumption was further supported by observing the low nutrient-to-cost ratios of the different ingredients and the low consumption of meat and seafood in the preliminary survey.

The mix was designed to fully cover the energy requirements of the child, thus assuming no breastfeeding during the period when the emergency rations are administered. This assumption was introduced in order to both simulate disaster conditions and subject the methodology to a more demanding test.

Local ingredient prices per consumable weight were obtained from a market in Maputo in February 2013. Prices were collected in the local currency, Mozambican meticais (MZN), and converted to US dollars (US$1 = 30 MZN). Estimates of prices of mineral supplements for comparing suitability of supplementation were obtained from online price lists of food suppliers in April 2014. Ten times the list price was used as a cost estimate for the supplement salts in order to take into account transport costs and uncertainty in prices.

The nutritional composition of each ingredient (raw) was obtained from the USDA database [32] when available. Data for cassava leaves were obtained from the food composition tables for Mozambique [38]. Lower and upper levels of macro- and micronutrient intakes for use in the linear programming were

TABLE 2. Nutritional constraints used in the linear programming analysis with nutrient compositions in the minimum-cost formulations for 1- to 2-year-old boys. The table also shows shadow prices of lower ($p_{S,min}$) and upper ($p_{S,max}$) constraints for each optimization[a]

Nutrient	Nutrient recommendations (1- to 2-yr-old boys)		Condition A: Local ingredients			Condition B: Local ingredients and calcium supplement			Condition C: Local ingredients and calcium and zinc supplements		
	Min	Max	Intake	p_S,min	p_S,max	Intake	p_S,min	p_S,max	Intake	p_S,min	p_S,max
Mass (g)	300	1,000	1,000	0	0	1,000	0	0	1,000	0	0
Energy (kcal)	1,200[b]	1,200[b]	1,200	950	950	1,200	280	280	1,200	250	250
Dry matter (g)	0	250	230	0	0	200	0	0	150	0	0
Fat (g)	30[c]	53[d]	30	0.063	0	30	0.062	0	30	0.054	0
Protein (g)	13[b]	60[d]	34	0	0	29	0	0	16	0	0
Carbohydrate (g)	130[e]	195[d]	130	0.061	0	130	0.056	0	130	0.059	0
Calcium (mg)	500[f]	2,500[g]	500	0.015	0	500	0	0	500	0	0
Iron (mg)	6[f]	40[g]	21	0	0	8.6	0	0	6.7	0	0
Vitamin A (μg)	300[c]	700[g]	700	0	0	300	0	0	300	0	0
Zinc (mg)	4[f]	7[g]	4.3	0	0	4.0	0.50	0	4.0	0	0

a. Shadow prices (p_S,min and p_S,max) are reported in US dollars per day and unit of mass. Shadow prices < 0.001 USD/day/(unit of mass) are indicated by 0.
b. Energy requirement [41].
c. Adequate Intake (AI) for infants 6 to 12 months old [40].
d. Based on ≤ 40% energy from fat, ≤ 20% energy from protein, and ≤ 65% energy from carbohydrates [40].
e. Recommended Daily Allowance (RDA) [40].
f. Recommended Nutrient Intake (RNI) [39].
g. Tolerable upper intake level [40].

TABLE 3. Nutritional constraints used in the linear programming analysis with nutrient compositions in the minimum-cost formulations for 1- to 2-year-old girls. The table also show shadow prices of lower (p_s,min) and upper (p_s,max) constraints for each optimization[a]

Nutrient	Nutrient recommendations (1- to 2-yr-old girls)		Condition A: Local ingredients			Condition B: Local ingredients and calcium supplement			Condition C: Local ingredients and calcium and zinc supplements		
	Min	Max	Intake	p_S,min	p_S,max	Intake	p_S,min	p_S,max	Intake	p_S,min	p_S,max
Mass (g)	300	1,000	1,000	0	0	1,000	0	0	1,000	0	0
Energy (kcal)	1,100[b]	1,100[b]	1,100	720	720	1,100	490	490	1,100	380	380
Dry matter (g)	0	250	230	0	0	200	0	0	150	0	0
Fat (g)	30[c]	49[d]	30	0.063	0	30	0.036	0	30	0.054	0
Protein (g)	13[b]	55[d]	32	0	0	29	0	0	15	0	0
Carbohydrate (g)	130[e]	179[d]	130	0.061	0	130	0.053	0	130	0.059	0
Calcium (mg)	500[f]	2,500[g]	500	0.015	0	500	0	0	500	0	0
Iron (mg)	6[f]	40[g]	21	0	0	8.9	0	0	6.4	0	0
Vitamin A (μg)	300[c]	700[g]	700	0	0	300	0	0	300	0	0
Zinc (mg)	4[f]	7[g]	4.0	0	0	4.0	1.1	0	4	0	0

a. Shadow prices (p_S,min and p_S,max) are reported in US dollars per day and unit of mass. Shadow prices < 0.001 USD/day/(unit of mass) are indicated by 0.
b. Energy requirement [41].
c. Adequate Intake (AI) for infants 6 to 12 months old [40].
d. Based on ≤ 40% energy from fat, ≤ 20% energy from protein, and ≤ 65% energy from carbohydrates [40].
e. Recommended Daily Allowance (RDA) [40].
f. Recommended Nutrient Intake (RNI) [39].
g. Tolerable upper intake level [40].

obtained from Food and Agriculture Organization (FAO) Recommended Nutrient Intakes (RNIs) [39] and USDA Recommended Daily Allowances (RDAs) [40] (or Adequate Intakes [AIs] when RNIs or RDAs were unavailable) (**table 2**). The bioavailability of minerals is influenced by diet. A moderate bioavailability was assumed for zinc and a 10% bioavailability for iron. FAO energy intake recommendations [41] differ for boys and girls aged 1 to 2 years. All constraints used for boys can be seen in **table 2**. The corresponding constraints for girls can be seen in **table 3**.

All linear programming optimizations were carried out using the simplex method algorithm, used as implemented in MATLAB 2014a. [42]

Results

As a first attempt, the composition of the minimum-cost relief porridge fulfilling all nutritional and consistency constraints was calculated using linear programming, as described above. Only the previously listed locally available foods were included in the analysis. The optimization successfully found solutions for both boys and girls. The full composition of the food can be found in **table 4** and is summarized in terms of ingredient categories in **table 5** (condition A). As seen in **table 5**, the porridges contain a large percentage of starchy flours, 55% (mainly in the form of roasted cassava and dehulled sorghum flours). Leaves and beans are included together with the starchy components to fulfill the nutrient constraints. However, the minimum price to achieve these constraints is high (US$0.37/day).

It can be seen from **table 5** that most micro- and macronutrients fall within the constraints for both age groups; however, not all constraints that are active have a large influence on price, as can be seen by looking at the shadow prices (see **table 2**). The micronutrient with the highest shadow price, by far, is calcium

TABLE 4. Detailed composition (per 100 g) of suggested porridge including only local ingredients (condition A)

Group	Ingredient	Boys	Girls
Starchy flours	Dehulled maize flour[a] (g)	0	0
	Dehulled sorghum flour[a] (g)	3.4	3.5
	Germinated maize flour[a] (g)	0	0
	Orange-fleshed sweet potato flour[a] (g)	0	0
	Roasted cassava (*garri* or *rale*) flour[a] (g)	4.2	4.7
Vegetable oil	Sunflower oil (g)	2.1	2.1
Nuts	Cashew nuts (dried) (g)	0	0
	Peanuts (dried) (g)	0	0
Fruits	Banana (g)	0	0
	Mango (g)	0	0
	Orange (g)	0	0
	Papaya (g)	0	0
Vegetables	Carrot (g)	0	0
	Pumpkin (g)	0	0
Rice	Rice (g)	0	0
Legumes and legume flours	Kidney beans (g)	3.0	2.2
	Cowpea flour[a] (g)	0	0
	Dehulled soybean flour[a] (g)	7.4	7.7
Leaves	Cassava leaves (g)	8.8	8.8
	Pumpkin leaves (g)	0	0
	Sweet potato leaves (g)	0	0
Supplements	Calcium citrate (mg)	NI	NI
	Zinc gluconate (mg)	NI	NI
Water	Water added during cooking (g)	71	71

NI, not included as an ingredient

a. Note that the table describes mass of the flours in the porridge mix, whereas **table 5** gives the mass percentages of the porridge. (Each porridge consists of swollen flour in water.)

TABLE 5. Summary of optimal porridge composition and total costs

	Condition A: Local ingredients		Condition B: Local ingredients and calcium supplement		Condition C: Local ingredients and calcium and zinc supplements	
Ingredient group	Boys	Girls	Boys	Girls	Boys	Girls
Starchy porridges (%)	55	55	89	85	91	91
Sunflower oil (%)	2.1	2.1	0.1	0	2.9	2.9
Fruits (%)	0	0	0	0	0	0
Vegetables (%)	0	0	0	0	0	0
Rice (%)	0	0	2.7	3.7	3.3	3.9
Leaves (%)	8.8	8.8	0	0	0	0
Nuts (%)	0	0	5.6	5.7	0	0
Beans (%)	34	34	2.7	5.3	3.2	2.3
Calcium citrate (mg)	NI	NI	1,600	1,600	1,800	1,800
Zinc gluconate (mg)	NI	NI	NI	NI	13	14
Total cost (USD/day)	0.37	0.37	0.23	0.24	0.21	0.21

NI, Not included as an ingredient

(US$0.015/mg/day for boys and girls alike). This finding suggests that the cost of the food can be reduced significantly if calcium is supplied through another source. Based on the high shadow prices, supplementation was investigated as a means of reducing the cost to feasible levels in a second optimization (condition B in **table 5**) by including calcium citrate as an ingredient. A summary of the new composition can be seen in **table 5** (full composition in supplementary **table 6**). The cost is reduced by 38% for boys and 35% for girls when supplementing with calcium.

Shadow prices for this second optimization reveal how to reduce the cost even further. Looking to the micronutrients, zinc has the highest shadow price (US$0.5/mg/day for boys and US$1.1/mg/day for girls). A third optimization (condition C in **table 5**) was run by including both zinc gluconate and calcium citrate supplements. The final composition can be seen in **table 5**. The supplemented porridge contains a higher percentage of the cost-effective starchy flours and lower concentrations of the more expensive nuts and beans. Supplementing with zinc allows a cost reduction of a further 13% to US$0.21/day. The total cost reduction from including supplements is 43%. **Table 5** is useful in illustrating the composition of the suggested porridges; however, since the porridges are themselves a mixture of flour and water, the final porridge composition in terms of primary ingredients is also shown in **table 7** for comparison.

Discussion

Feasibility of obtained porridge

In summary, the results show that the linear programming methodology with the consistency constraint does arrive at a porridge fulfilling both consistency and nutrient constraints for both boys and girls. Furthermore, the solutions for boys and girls are very similar, showing that the algorithm is insensitive to small variations in energy requirements. In many cases, linear programming fails to produce a feasible diet, especially when setting a large number of constraints and

TABLE 6. Detailed composition (per 100 g) of suggested porridge including local ingredients and calcium supplementation (condition B)

Group	Ingredient	Boys	Girls
Starchy flours	Dehulled maize flour[a] (g)	0	0
	Dehulled sorghum flour[a] (g)	5.8	5.5
	Germinated maize flour[a] (g)	0	0
	Orange-fleshed sweet potato flour[a] (g)	5.0	5.0
	Roasted cassava (*garri* or *rale*) flour[a] (g)	0	0
Vegetable oil	Sunflower oil (g)	0.1	0
Nuts	Cashew nuts (dried) (g)	0	0
	Peanuts (dried) (g)	5.6	5.7
Fruits	Banana (g)	0	0
	Mango (g)	0	0
	Orange (g)	0	0
	Papaya (g)	0	0
Vegetables	Carrot (g)	0	0
	Pumpkin (g)	0	0
Rice	Rice (g)	2.7	3.7
Legumes and legume flours	Kidney beans (g)	2.7	1.8
	Cowpea flour[a] (g)	0	0
	Dehulled soybean flour[a] (g)	0	0.84
Leaves	Cassava leaves (g)	0	0
	Pumpkin leaves (g)	0	0
	Sweet potato leaves (g)	0	0
Supplements	Calcium citrate (mg)	1,600	1,600
	Zinc gluconate (mg)	NI	NI
Water	Water added during cooking (g)	78	77

NI, not included as an ingredient

a. Note that the table describes mass of the flours in the porridge mix, whereas **table 5** gives the mass percentages of the porridge. (Each porridge consists of swollen flour in water.)

including only local foods available in developing countries [17]. The finding that the linear programming algorithm successfully arrives at a solution in all cases is a promising result; however, it cannot be generalized to all foods, lists of ingredients, or age groups. Generally, adding more nutritional constraints increases the risk of failing to find a solution. Younger children require more energy- and nutrient-dense foods, which is more challenging for the methodology. As a stress test, optimizations were repeated with a reduced upper total mass constraint, simulating an increased nutrient and energy density requirement. Even when the limit was reduced to 300 g/day (a third of the original estimation used above), feasible porridges were obtained; however, the cost increased (by 22%).

The present analysis does not include cultural constraints on the amount of the different ingredients or groups of ingredients. However, all ingredients included in the analysis are commonly grown in the area and consumed by adults and children. The obtained porridges have a high percentage of starchy flours, especially when external supplementation of trace minerals is assumed (see conditions B and C in **table 5**). Putting an upper limit on the amount of starchy flours, as has been done in studies on diets [16, 17], would not be a reasonable cultural constraint for the porridges in this study, since starchy flours in general and roasted cassava flour in particular constitute the major part of the diet for many families in rural Mozambique at present [43].

The introduced consistency constraints make sure that the thickness of the obtained porridges before nonstarchy ingredients are added is comparable to that of commercial porridges designed for and consumed by children of the relevant age group. The final mix suggestion in **table 5** (condition C) is an almost binary mixture (91%) of dehulled sorghum and orange-fleshed sweet potato, which has been shown experimentally to give a consistency in the range of commercial babyfood porridge formulations [31]. The upper limit on dry matter makes sure that the remaining ingredients do not make the porridge too thick. As shown in **table 2**, the supplemented mix has a low dry matter content (15%). This is in the range of commercial products. The USDA database [32] lists four commercial baby foods for toddlers 1 to 3 years old, and the dry matter

TABLE 7. Detailed composition (per 100 g) of suggested porridge including calcium and zinc supplements (condition C)

Group	Ingredient	Boys	Girls
Starchy flours	Dehulled maize flour[a] (g)	0	0
	Dehulled sorghum flour[a] (g)	6.0	6.0
	Germinated maize flour[a] (g)	0	0
	Orange-fleshed sweet potato flour[a] (g)	5.0	5.0
	Roasted cassava (*garri*) flour[a] (g)	0	0
Vegetable oil	Sunflower oil (g)	2.9	2.9
Nuts	Cashew nuts (dried) (g)	0	0
	Peanuts (dried) (g)	0	0
Fruits	Banana (g)	0	0
	Mango (g)	0	0
	Orange (g)	0	0
	Papaya (g)	0	0
Vegetables	Carrot (g)	0	0
	Pumpkin (g)	0	0
Rice	Rice (g)	3.3	3.9
Legumes and legume flours	Kidney beans (g)	3.2	2.3
	Cowpea flour[a] (g)	0	0
	Dehulled soybean flour[a] (g)	0	0
Leaves	Cassava leaves (g)	0	0
	Pumpkin leaves (g)	0	0
	Sweet potato leaves (g)	0	0
Supplements	Calcium citrate (mg)	1,800	1,800
	Zinc gluconate (mg)	13	14
Water	Water (g)	80	80

a. Note that the table describes mass of the flours in the porridge mix, whereas **table 3** gives the mass percentages of the porridge. (Each porridge consists of swollen flour in water.)

contents of these vary between 7% and 18%.

Taste constraints are not included in the present analysis, since taste is considered secondary to consistency and nutrition under relief conditions. Traditionally, when it is available, sugar is added to the starchy porridges, such as porridge made with roasted cassava flour (a product locally known as *garri* or *rale*), to improve taste. Adding sugar to the optimal mixes would not significantly increase energy intake; adding up to 3 tablespoons of granulated sugar to each daily intake would not increase energy consumption by more than 4% (energy data from USDA [32]). However, any addition of sugar would imply a higher-than-optimal price and also would have adverse effects on the percentage of energy from carbohydrates. Finally, it has also been argued that a high concentration of sorghum (as obtained in the suggested recipe) could have a beneficial effect on taste in similar products [29]. A final test of acceptability requires the use of consumer trials and sensory evaluation. Planning and carrying out such studies is an important next step in further validating the methodology.

The nutrient compositions reported in this study are based on raw ingredients. Cooking, which is required when preparing the suggested porridge, generally influences nutrient composition. In this case, the limiting micronutrients, such as zinc and calcium, are not easily degraded by heat. However, the carotenoids that are precursors of vitamin A are influenced by cooking conditions [44]. It would be an interesting extension of the analysis to include cooking time and temperature as independent variables in the optimization to determine the optimal amount and type of preparation to obtain acceptable consistency while fulfilling nutrient constraints and minimum cost.

In developing countries, the food is often plant-based. This is frequently associated with deficits of micronutrients such as iron, zinc, and calcium, induced in part by poor bioavailability, especially when the complementary food is based on unrefined cereals and legumes are used. The effect is aggravated by a high content of phytate, a potential inhibitor of mineral absorption [9, 45, 46]. Thus, a complete nutrient optimization routine should automatically adjust the micronutrient limits as a function of the antinutrients included. This effect is complex and has not yet been included in the nutrient evaluation in the linear programming methodology. This study, like previous studies [47], is based on an assumed constant bioavailability. A more comprehensive treatment of bioavailability and absorption could also be used to better determine whether the assumption of a meat-free ingredient list can be sustained. However, the assumption of constant bioavailability is not expected to influence the feasibility of the methodology, since reduced bioavailability of the limiting minerals could be moderated by adding more supplement salts, which can be done without influencing cost or consistency.

Limiting nutrients and economic implications

The dry mix porridge example is intended as a relief and emergency food for extreme situations. However, it also describes the minimum cost of a complete nutritious baby food with agreeable consistency based on locally available and culturally consistent ingredients. Therefore, it does offer further insight into the cause of child malnourishment in the region.

In summary, the results show that a nutritious porridge with acceptable consistency could be designed using local ingredients; however, the cost will be very high if supplements are not available. The average family size of five children [35] and the food cost per child in the example would result in a total cost of US$1.85/day. This is unsustainable in an economy where 50% of the population has an income below US$1.25/day [34]. The high prices obtained in the supplement-free optimization (condition A in **table 5**) show that it is challenging for rural families to prepare foods for children that meet the daily recommendations using local ingredients within a tight budget. This is in line with conclusions from previous diet optimization performed on the same region [48]. Moreover, the present study shows that the cost is increased further by including the consistency constraints. Requiring a more realistic diet is expected to increase the cost even further. In summary, increased nutritional awareness and information campaigns alone cannot solve child malnourishment in the region.

The porridge example also shows the value of using shadow prices in order to determine the influence of different micronutrients. Although several of the micronutrients fall within the lower bound of the respective constraint, they do not all influence the minimum porridge price to the same degree. For example, vitamin A deficiency is a problem for young children in the developing world, with an estimated prevalence of 71% in children aged 6 to 59 months in Mozambique [49, 50]. However, looking for the limiting nutrient and the shadow price in our study, it should be easy to fulfill vitamin A requirements, assuming that households include ingredients with a cost-efficient concentration of vitamin A, such as green leaves and orange-fleshed sweet potato. This implies that vitamin A deficiency is not caused by economic constraints and could be solved by making the already available vitamin A–rich ingredients more acceptable (see, for example, De Carvalho et al. [51]).

In contrast, zinc does constitute an economically limiting nutrient; it would not be possible to improve zinc deficiency by dietary changes without significantly increasing the cost of the food. Alternative foods rich in zinc, such as seafood and meat, are either unavailable or expensive and so would not solve the problem. Thus, based on the shadow price analysis, it could be argued that supplementation is necessary for zinc but not for vitamin A.

Linear programming for food design

This study adds consistency constraints to linear programming as a step toward extending the methodology commonly used for dietary design recommendations for soft porridges. However, different types of food need different consistency constraints, and consistency is not the only sensory variable of importance for food formulation. Including constraints on other sensory aspects, such as taste, flavor, and general mouthfeel parameters, would be an interesting continuation of the present work. This would require more experimental studies analogous to those of De Carvalho et al. [30, 31] on how mixtures of common ingredients influence these properties in order to find and formulate relevant constraints. This continued extension of linear programming for nutritional use is not only of importance for obtaining more feasible diets and foods; the growing use of linear programming to draw conclusions on policies and relief programs [21, 23, 24, 52] is dependent on the inclusion of refined constraints to further support the feasibility of the optimal compositions.

Conclusions

The objective of this study was to extend the linear programming methodology from diets to foods by including consistency constraints in order to increase feasibility and to aid in diet implementation. Consistency constraints for soft porridges were included based on empirical studies of swelling behavior and limits on dry matter content. The method was exemplified using a minimum-cost emergency relief food formulation based on local ingredients fulfilling nutrition constraints. The optimizations were successful in finding formulations that fulfill all constraints; however, the cost was unreasonably high when only locally available ingredients were included. Reasonable cost requires the inclusion of supplements for mineral salts, due to the high cost of local ingredients rich in minerals. After allowing for mineral supplements, a food with a feasible price, an acceptable consistency, and what by comparison would be expected to be a culturally agreeable composition was obtained. The example shows that the extended methodology produces reasonable results for a challenging case and offers a promising methodology for designing nutritious foods for combating malnourishment.

Acknowledgments

This study was supported by the Swedish International Development Agency (SIDA).

The authors wish to thank Ieva Sateikate for performing the survey of eating habits used in choosing the porridge ingredients and Dr. Lucas Daniel Tivana for help with collecting prices of the ingredients in rural markets in Mozambique.

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